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THE JOURNAL OF
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THE EIGHTH KELVIN LECTURE.

SOME ASPECTS OF LORD KELVIN'S LIFE AND WORK.

By Dr. ALEXANDER RUSSELL, Vice-President.

(*Lecture delivered before* THE INSTITUTION 9 *November*, 1916.)

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Since the last Kelvin lecture was given we have to lament the loss of Silvanus Thompson, the first Kelvin lecturer. We shall sadly miss his frequent contributions to our debates—always admirable in every way—his enthusiasm for electrical discovery, and his kindly criticism. But most of all we shall miss his generous and unsparing help at our Council and Committee meetings.

We have also to lament the loss of Sir William Ramsay, whose great discoveries, argon, helium, neon, krypton, xenon and the relationship between radium and helium, have placed him for all time in the front rank of philosophers. In early life Ramsay came much in contact with Kelvin, who was a friend of his father. Kelvin was one of the first to detect the genius of young Ramsay, and when he was his pupil he did his best to develop his ability. In after years Ramsay always gratefully remembered the kindness of his old friend and professor. In later life he enjoyed nothing better than giving reminiscences of him to his friends (see Appendix 1).

1. EARLY TRAINING AT GLASGOW.

The period of Kelvin's life which is of the greatest human interest and well deserves special study by educationalists is from his eighth to his sixteenth year. His father, James Thomson, was appointed to the Chair of Mathematics in Glasgow University in William's (Lord Kelvin's) eighth year. We know that when William was eight years old, he and his elder brother James attended unofficially their father's junior mathematical class. It is recorded that William once electrified the class by asking his father's permission to answer a question. His own family had the highest possible opinion of his ability. When he was 10 years old he matriculated at Glasgow University and went through the Arts Course, going up to Cambridge at the beginning of his seventeenth year.

His father carefully superintended William's course at Glasgow, fostering his love for physical science and giving him judicious help in his mathematical and classical studies. Although a strict disciplinarian he never alienated the affection of his children. In his later life Kelvin often recalled that all that he had learnt as a boy in English, geography, history, mathematics, and classics, was taught him at home along with his brothers and sisters by his father. He used also to add that he never met a better teacher in anything than his father was in everything.

During his course at Glasgow he studied under several famous professors and won distinction by carrying off most of the prizes. The preparing for examinations at this period encouraged that hot intemperate method of study which caused in after years so much anxiety to the second Lady Thomson.[*] Luckily, however, the Glasgow session lasted only during the six winter months, and so Professor Thomson and his family could spend a considerable part of the summer vacation in holiday-making. The letters of the family show how much they all liked these happy months at villages on the Firth of Clyde. William then acquired that lifelong love for navigational problems and for the

> "Billow and breeze, islands and seas,
> Mountains of rain and sun,"

which are typical of the West Coast of Scotland. The swimming, boating, and mountaineering in which he then delighted both accentuated his mental activity and perfected his bodily health. He read and studied mathematical works assiduously, being eager to qualify himself to attack those physical problems about which he had heard so much at college. One of his favourite books was De Morgan's "Differential and Integral Calculus." Some of the difficulties in this book were doubtless explained to him by his father, but the reading of it he regarded as relaxation as it gave him great pleasure.

His last year at Glasgow University was one of unexampled mental activity. Some years later on looking back on this period he said that "his mental vision was clearer then than it was now." He had little desire to read novels and read very few. In fact from 1840 to 1843 he read none.

It would be very unsafe to deduce any general rules for the education of genius from Thomson's early life. The main features in his case are an experienced father anxious to teach and a bright son willing to learn. He did not need the inducement of prizes in order to excel, although he gained many. To play truant would have been abhorrent to him. R. L. Stevenson, one of the most brilliant of authors, has boasted that no one ever played truant with more deliberate care than he did himself, and that no one ever had more certificates for less education. The Arts Course of the Scotch universities so admirable for Thomson was neither interesting nor attractive to one like Stevenson, endowed with a strong literary and artistic temperament.

William Thomson's elder brother James, who was afterwards professor of engineering at Glasgow University, was a thoughtful and thorough student who was much loved by his friends. He was less brilliant than his younger brother, but no trace of jealousy ever shadowed their affection. Their sister Mrs. King in "Lord Kelvin's Early Home" tells how both James and William made frictional electrical machines when they were boys. The one James made was more ambitious and better designed from the mechanical point of view, but William's worked quite satisfactorily. Even the smell of ozone proved attractive to the Thomson family, who used to call it "sulphur and phosphorus."

Before Thomson came up to Cambridge he wrote a paper criticizing a theorem given in Kelland's "Theory of Heat." The paper is purely mathematical, and is a remarkable production for a boy of sixteen. It was the forerunner of many hundreds of papers, some of which opened up unexplored regions of science and all of which were characterized by clear thinking and deep physical insight.

2. ELECTROSTATICS.

The first important paper of Thomson's was written four months later, just before he entered Peterhouse, Cambridge, as a freshman. It was entitled "On the Uniform Motion of Heat in Homogeneous Solid Bodies, and its Connection with the Mathematical Theory of Electricity." He points out how the problem of the flow of heat in a conducting solid is exactly analogous to the problem of the electrostatic field in an insulating medium. The lines of flow in the heat problem are coincident with the lines of force in the corresponding electrostatic problem.

It follows at once from his reasoning that if Q be the quantity of heat flowing per second from a body at a temperature θ, embedded in an infinite medium of conductivity k, the boundary of the medium being at zero temperature, then, when the flow is steady, $Q/\theta =$ a constant $=$ the thermal conductance of the medium $= (4\pi/\lambda)kC$, where C is the electrostatic capacity of a conductor placed in a medium of inductivity λ.

Similarly we may show that if R be the electric resistance between an excellently conducting solid, placed in a medium of volume resistivity ρ, and the boundary of the medium, then $RC = \rho\lambda/4\pi$. Hence from the mathematical point of view the problems of thermal conductance, electrostatic capacity, and electric resistance are the same.

It is shown in Appendix 2 that if S be the surface of a conductor, then in very many cases we have to a high degree of approximation that its capacity C is given by

$$C = (S/4\pi)^{\frac{1}{2}}.$$

Hence by Thomson's analogy this formula also helps us to study how the resistance of the "earth" of an earthed conductor varies with the shape of the conductor which is in contact with the ground. It also shows how the thermal conductance of a medium varies with the shape of a hot conductor embedded in it.

It readily follows from Thomson's paper that the thermal conductance between two isothermal surfaces at temperatures θ_1 and θ_2, i.e. $Q/(\theta_1 - \theta_2)$, equals $(4\pi/\lambda)kC$, where C is the "capacity between the two surfaces" in the corresponding electrostatic problem. This is the "capacity" which electrical engineers use. Looked at from this point of view it will be seen that the conceptions of the "capacity" of a body and the "capacity between two bodies" are really the same. The capacity of a conductor is the capacity between its boundary, which is an equipotential surface, and the equipotential surface of zero potential.

In this paper Thomson gives a clear statement of Green's theorem, which he like Gauss, Sturm, and Chasles had independently discovered.

3. CAMBRIDGE.

In 1843, William Thomson rowed in the May races at Cambridge, first as No. 7 and then as bow, and was largely instrumental in preventing the Caius boat, which had a great reputation, from bumping Peterhouse. Six months later he won the Colquhoun sculls. In these days the racing boats had thole pins and were old-fashioned. Hence the experience he gained in the summer holidays boating on the Firth of Clyde stood him in good stead. It is related that at the end of the race for the silver sculls he was very exhausted, having done very little training for it.

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[*] Appendix 1.

In 1845, he was second wrangler and first Smith's prizeman. He therefore felt that he was free to devote himself whole-heartedly to investigating physical problems with the help of mathematics. He specially studied the problem of the distribution of electricity on two spherical conductors when near one another. Poisson as early as 1812 had obtained the complete mathematical solution of this problem, but his solution was not adapted to numerical computation. Sir William Snow Harris in a paper published in the *Philosophical Transactions* for 1834 describes very careful experiments he had made to measure the attractions between spherical conductors. His results seemed to throw doubt on the accuracy of Coulomb's law. He found, for instance, that when two equal spherical conductors had unequal charges of the same sign, then if they were initially far apart they repelled one another, but if they were close together initially they attracted one another. When very close together a spark passed from one to the other and repulsion again ensued. At a certain distance apart they were in neutral equilibrium provided that the charges were of the same sign and unequal in magnitude (see Appendix 3).

4. ELECTRIC IMAGES.

Thomson therefore attacked the problem of calculating the mutual attractions and repulsions of the two electrified conductors, and obtained a complete solution from which numerical values could be found without very much difficulty. In obtaining this solution he used the method of "electric images" with which his name will always be associated. He shows that if we have two conducting spheres with given electric charges the field round the conductors can be exactly reproduced by an infinite series of point charges placed at certain definite points inside the two spheres and on the line joining their centres. This method is useful in the theories of heat, hydrodynamics, sound, etc., and also in pure mathematics. Robert Murphy (see Appendix 4) had previously suggested in his book on "Electricity," published in 1833, how an approximate solution could be obtained by a method which he called the "method of successive influences." Thomson refers to this method and shows that the effects of the successive induced charges can be produced by means of image charges.

Thomson proved that the behaviour of electrified conductors as described by Snow Harris was in exact accordance with theoretical deductions from Coulomb's law. He also criticized, mistakenly in the author's opinion, certain of Snow Harris's experimental results. Although Snow Harris was certain that his experimental results were accurate he was most impressed by the ability of the young Scottish mathematician.

It was not, however, until 1853 that Thomson published the solution of the problem and gave a table and formulæ by means of which the attractions, capacities and neutral distances of the two spheres can be easily and accurately found, provided that they are not too close together. When a very young man, Thomson published the solutions of several important problems without, however, publishing the methods by which they were obtained. For instance, in a letter to Liouville in 1846 he gives the solution of the problem of the distribution of electricity on a spherical bowl—one of his greatest achievements. The method of solving the problem, however, was not published until 23 years later. During this period no other mathematician had been able to supply a proof. In 1881, however, Norman Macleod Ferrers gave a proof by another method.

It is highly probable that Donald Macfarlane, Thomson's assistant, worked out most of the numerical calculations in the paper discussing the attractions and repulsions of spheres. Thirty-three years later, Kirchhoff checked some of the calculations, and the author checked them all by means of simplified formulæ in 1909. The result reflects the greatest credit on the accuracy of Macfarlane's work.

If the potentials of the two equal spheres are v and $-v$ respectively, and if F be the attraction between them, it can be proved by Coulomb's law that

$$F = \alpha\,(a/c)^2\,v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a is the radius of either sphere, c the distance between their centres, and α a number that depends only on the value of a/c. Values of α are given in the *Journal I.E.E.*, 1912, vol. 48, p. 265. In (1), F is in dynes, and v is measured in absolute electrostatic units.

For instance, if c is 3 and a is 1, we have, on the assumption that the dielectric coefficient of air is unity,

$$F = 0{\cdot}3178\,v^2 \text{ dyne nearly,}$$

where v is in electrostatic units. Assuming Maxwell's theory and knowing that the velocity of light is 3×10^{10} cm. per second, we find that the unit of electrostatic pressure is 300 volts. Hence if the potentials in volts of the two spheres be V and $-$ V respectively, we have

$$F = 0{\cdot}000003531\ V^2 \text{ dyne.}$$

For example, if $V = 15{,}000$ volts, we have

$$F = 794{\cdot}5 \text{ dynes} = 0{\cdot}8097 \text{ gramme weight.}$$

Conversely, by weighing the attraction F between the spheres we can readily find the voltage 2 V between them. This method can easily be applied to measure the voltage of high-pressure transformers. It is to be noticed that the voltage is completely determined when the dimensions of the spheres and the force of attraction between them are given. In standardizing a voltmeter of this kind no electrical measurements are necessary. The spheres, however, must not be too near to one another otherwise a spark will pass between them.

5. ABSOLUTE UNITS.

In the fourth Kelvin lecture, Dr. Glazebrook has given us the history of the absolute units, beginning with the appointment of the Electrical Standards Committee of the British Association in 1861. But 10 years before this Thomson had found that all the effects of electromagnetic and electrodynamic induction could be explained by the principle of the Conservation of Energy—a principle first clearly enunciated by George Green (see Appendix 5). In the *Philosophical Magazine* for December 1851 appeared Thomson's remarkable paper on the "Applications of the Principle of Mechanical Effect to the Measurement of Electromotive Forces and of Galvanic Resistance in Absolute Units." Since the E.M.F. of the electrochemical action in a cell equals the dynamical equivalent of the whole chemical change effected by a current of unit strength in a second, the E.M.F. of a Daniell cell can be calculated (1) on the assumption that the whole chemical action is electrically efficient, or (2) on the assumption that only the oxidation or deoxidation of the metals is electrically efficient. The true value of the electromotive force we now know to be about 1·07 volts. Making the first assumption Thomson obtains 2,570,300 foot-grain-second units, that is, 1·101 volts as the E.M.F. of a Daniell cell, and on the second he gets 0·995 volt. He also found that Joule's experimental results made the value 1·074 volts. Although his theory is not rigorous the results obtained are wonderfully accurate.

In this paper Thomson points out that if H be the heat developed in a wire and J be Joules' equivalent we have J H = E I, and therefore by Ohm's law, J H = R I². Hence since J and H are known and I can be measured at once, in absolute units (by a tangent galvanometer for instance), R is found and therefore also E. The values of the C.G.S. units of current, resistance, and electromotive force can thus be found. It is obviously of the greatest importance that all experimenters should use the same units. Previous to Thomson's paper they could only be expressed in terms of apparatus, cells, and wires in the possession of the observers. In many cases, therefore, it was impossible to compare their results. The idea of measuring resistance in absolute units was due to W. Weber, and Kirchhoff made the first determination in 1849. Thomson was the first, however, to show how the fundamental electric units could be determined from the principle of energy.

Thomson defines the volume resistivity ρ and the mass resistivity ρ' of the copper forming a wire by the equations

$$R = \rho l/A \quad \text{and} \quad R = \rho' l^2/m$$

where R is the absolute resistance of the wire, l its length, and m its mass. He then compares the resistivity of the wire used by Jacobi, Kirchhoff, Weber, and Joule, the values being given in foot-grain-second units. At this date it will be seen that Thomson had very clear views about the electrical units, and the work of the British Association Committee of which he was one of the original members was to make standards for these units, a task which presented many difficulties until accurate methods of measuring were invented.

Thomson was a severe critic of Weber's theory that an electric current consists of the motion of particles of two kinds of electricity moving in opposite directions. Weber assumed that the forces exerted by these particles on other particles of electricity when in relative motion are different from those they would exert when at relative rest. Thomson points out that Weber's assumptions are quite unwarrantable. As his conclusions also are inconsistent with the Conservation of Energy they must be wrong.

6. ELECTRIC OSCILLATIONS.

In 1853, Thomson read an epoch-making paper on the "Oscillatory Discharge of a Leyden Jar" to the Glasgow Philosophical Society. Six years previously, Helmholtz had discussed a puzzling phenomenon; he had noticed when a steel knitting needle was magnetized by the discharge current from a Leyden jar. In some cases the needle was left magnetized with the north pole at one end, and sometimes with the north pole at the other. If the discharge were oscillatory this would explain these results. Thomson proved mathematically that this was true in certain cases and obtained a formula by means of which the rapidity of the oscillations can be computed. He suggested also that an experimental verification of this might be obtained by means of Wheatstone's revolving mirror. Feddersen did this in 1859. The invention of the oscillograph has enabled us to study these discharge currents in detail and prove that Thomson's theory is very approximately correct. The great practical importance of this paper lies in the fact that it led many physicists to study the problems of oscillatory discharge most carefully, and wireless telegraphy was the direct although unexpected outcome of their labours. It has to be remembered, however, that Thomson's theory is not complete. Of the energy originally stored in the jar we know that some is radiated into space. In many cases this amount is negligibly small and Thomson's theory is directly applicable. But he did not show how the radiated energy could be taken into account or state the limitations of his formulæ.

7. PERISTALTIC INDUCTION.

In the *Proceedings* of the Royal Society for May 1856, Thomson published a paper on the "peristaltic induction" of electric currents. The phenomena observed when testing submarine cables proved to him that the capacity effects between a wire and the sheath, or between neighbouring wires, were most important. In this paper he neglects the effect of electromagnetic induction as this is permissible for slow signals. Thomson had very clear views about the electrostatic coefficients of neighbouring conductors. His work on the forces between electrified spheres proves this. He saw that when we have several wires in a cable and they have static charges the potentials of each wire can be found by means of these coefficients. This is still true when the charges are in motion. "They present a very perfect analogy with the mutual influences of a number of elastic tubes bound together laterally . . . and surrounded and filled by a liquid which is forced through one or more of them." Borrowing a medical term he called this "peristaltic" induction. As the electricity was in motion it seemed to him illogical to talk about "electrostatic induction."

In the case of a submarine cable with three wires symmetrically placed inside it, we have

$$e_1 = p_{11} q_1 + p_{12} q_2 + p_{12} q_3,$$
$$e_2 = p_{12} q_1 + p_{11} q_2 + p_{12} q_3,$$
and
$$e_3 = p_{12} q_1 + p_{12} q_2 + p_{11} q_3,$$

where e_1 is the potential of No. 1 wire at the point whose abscissa is x, q_1, q_2 and q_3 the charges on the three wires per unit length at this distance from the origin, and p_{11} and p_{12} the coefficients of potential.

Neglecting electromagnetic induction which is permissible in slow signalling, we have

$$e_1 - \left(e_1 + \frac{\partial e_1}{\partial x}\,\delta x\right) = r\,\delta x\,c_1,$$

that is
$$-\frac{\partial e_1}{\partial x} = r\,c_1,$$

where r is the resistance per unit length of any of the wires. We also have

$$i_1 - \left(i_1 + \frac{\partial i_1}{\partial x}\partial x\right) = \frac{\partial}{\partial t}(q_1 \partial x)$$

and so
$$-\frac{\partial i_1}{\partial x} = \frac{\partial q_1}{\partial t}.$$

Hence we see that

$$\frac{\partial q_1}{\partial t} = -\frac{\partial i_1}{\partial x} = \frac{1}{r}\frac{\partial^2 e_1}{\partial x^2}$$
$$= \frac{p_{11}}{r}\frac{\partial^2 q_1}{\partial x^2} + \frac{p_{12}}{r}\frac{\partial^2}{\partial x^2}(q_2 + q_3)$$

and two similar equations.

Therefore, writing $q = q_1 + q_2 + q_3$, $\sigma_1 = 2q_1 - q_2 - q_3$, . . . we get

$$\frac{\partial q}{\partial t} = \left(\frac{p_{11}}{r} + \frac{2p_{12}}{r}\right)\frac{\partial^2 q}{\partial t^2}$$

and
$$\frac{\partial \sigma}{\partial t} = \left(\frac{p_{11}}{r} - \frac{p_{12}}{r}\right)\frac{\partial^2 \sigma}{\partial x^2},$$

where σ stands for σ_1, σ_2, or σ_3. The solutions of these equations were given by Fourier and are well known. Hence since $q_1 = \frac{1}{3}(q + \sigma_1)$, $q_2 = \frac{1}{3}(q + \sigma_2)$, and $q_3 = \frac{1}{3}(q + \sigma_3)$, the problem can be completely solved when the initial conditions are given. In a similar way Thomson shows how the solution for a two-wire, a four-wire, and a six-wire submarine cable can be found.

It will be noticed that the solutions of these problems are also the solutions of three-phase, single-phase, two-phase, and six-phase power-transmission systems. He left out of account the leakage conductance and the electro magnetic coefficients. But for a first solution of the problem it is wonderfully complete. The values of p_{11}, p_{12} may be difficult to calculate, but they can be measured experimentally with the greatest ease.

Thomson's equations can easily be made rigorous and give the complete solution of the electric transmission of power in a polyphase system. Let us take for instance the case of a symmetrical three-phase system. Let s be the leakage conductance per unit length of any one of the mains, and let k_{11} and k_{12} be their self and mutual capacity coefficients per unit length. Then we get

$$-\frac{\partial i_1}{\partial x} = s e_1 + k_{11}\frac{\partial e_1}{\partial t} + k_{12}\frac{\partial}{\partial t}(e_2 + e_3).$$

Reciprocating this equation we get

$$-\frac{\partial e_1}{\partial x} = r i_1 + l_{11}\frac{\partial i_1}{\partial t} + l_{12}\frac{\partial}{\partial t}(i_2 + i_3)$$

where l_{11} and l_{12} are the self and mutual inductance coefficients per unit length.

Since the system is symmetrical we have $i_1 + i_2 + i_3 = 0$, and $e_1 + e_2 + e_3 = 0$. Thus

$$-\frac{\partial i_1}{\partial x} = s e_1 + (k_{11} - k_{12})\frac{\partial e_1}{\partial t}$$

and
$$-\frac{\partial e_1}{\partial x} = r i_1 + (l_{11} - l_{12})\frac{\partial i_1}{\partial t}.$$

The solutions of these equations are well known.*

The point to be noticed is that these equations are only a slight extension of the equations Thomson solved in 1851. His thorough mastery of the problem of the electrostatic induction between two spheres had given him absolute faith in his electrostatic coefficients. We have shown above how easily his method can be expanded so as to take leakance and electromagnetic induction into account. The solution of the equations although laborious presents no difficulty to the mathematician.

8. ATLANTIC CABLE.

The first attempt to lay a cable across the Atlantic was made in 1857. It broke in 2,000 fathoms of water 330 miles west of Valentia. In 1858 it was decided that the U.S. frigate "Niagara" and H.M.S. "Agamemnon" should steam in opposite directions each with half the cable on board and splice it in mid-ocean. Professor Thomson acted as engineer in charge of the electrical testing on broad the "Agamemnon." After many mishaps the cable was safely laid on the 6th August, 1858, and some messages were sent. On the 6th September of this year messages ceased to pass and Thomson and the other engineers were appointed to report on the cause of the breakdown. In experimenting with the cable from the Valentia end, Thomson found that it acted in the same way as if it were an insulated copper conductor 270 miles long with its end connected with a copper plate sunk at this distance in the Atlantic. He took the opportunity of investigating the earth currents in it. He proved that electromagnetic induction due to the diurnal variations of terrestrial magnetism was a prominent cause, but he failed to trace the other disturbing cause or causes. A day seldom passed without the direction of the earth current changing several times. So far as he was able to see, however, there was no connection between the times of reversal of current and the solar hours.

In 1865 and 1866 Thomson acted as electrical engineer during the laying of the second and third Atlantic cables. He also acted as consulting engineer for various cable companies.

The troubles experienced with the 1858 cable led Thomson to invent the mirror galvanometer. The "ironclad" mirror galvanometer used with this cable is kept with other historical apparatus in the laboratory at Glasgow University. This was replaced by the spark recorder and finally by the siphon recorder. The arrangement of the suspended coil and magnets in this latter device is the same as in ordinary moving-coil galvanometers. Thomson was at this time a member of the firm of Thomson, Varley, and Jenkin, consulting engineers, which is well remembered by our older readers.

9. SPARKING DISTANCES.

In 1860, Thomson read a paper to the Royal Society on the "Measurement of the Electromotive Force required to produce a Spark in Air between Parallel Metal Plates at Different Distances." He used his absolute electrometer to measure the voltage, and was very surprised to find that the potential gradient required to break down a very thin stratum of air was greater than that required to break down a thicker stratum. He saw, however, that when the disruptive voltage exceeded several thousand volts the potential gradients at which the discharge occurred were practically constant.

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* A. RUSSELL: "Alternating Currents," vol. 2, chap. 20, 2nd Ed.

It is [illegible] to remember that these experiments were carried out in the cellars and laboratories of the Old Glasgow College practically next door to the workshop in which James Watt invented the condensing steam engine. Few appreciate the difficulties that had to be overcome in equipping a research laboratory in these early days. His assistants, also, were willing but untrained students. John Kerr (Appendix 6), the great physicist, used often to tell how he did research work from 1846 to 1849 in the "coal hole" in which Thomson had set up the first physical laboratory in Great Britain. Kerr was then a divinity student. In later years he used sometimes to come to Thomson's senior class. In 1882 the author remembers Thomson gracefully introducing him to the rest of the class as one of his most distinguished old pupils.

Thomson's paper on sparking distances was the first of the long series of papers on this subject which have been published by physicists in almost every country. The electrodes generally employed are spherical. The results prove that the voltage at which the disruptive discharge occurs, or at which a corona first appears, depends on the maximum value $R_{\max.}$ of the potential gradient, provided that the electrodes are farther apart than about one-tenth of an inch.

If the electrodes are spheres of radius a at a distance x cm. apart, and if the potentials of the electrodes at the instant of the discharge are E/2 and —E/2 respectively, we have, approximately,

$$E = 27{\cdot}2\,f\,\text{[illegible]}\left(1 + \frac{0{\cdot}54}{\sqrt{fa}}\right) \text{ kilovolts,}$$

where $f = 3{\cdot}92\,h/(273 + t)$, h being the height of the barometer in centimetres, t the temperature Centigrade and the values of f are given in the *Journal I.E.E.*, 1908, vol. 40, p. 9.

[illegible] if $h = 76$ cm. and $t = 25°$ C., then $f = 1$. Hence if the radius of each of the spheres be 1 cm. the sparking voltage when x is ½ cm. is 18 kilovolts, and when x is 1 cm. is 31 kilovolts. A full discussion of this formula and its limitations is given by F. W. Peek in the *Transactions* of the American Institute of Electrical Engineers, 1914, vol. 33, p. 923.

In the important case, from the engineering point of view, of overhead cylindrical wires the voltage at which the corona or brush discharge appears can easily be calculated. From the experiments of J. B. Whitehead and F. W. Peek it follows that if we have two parallel cylindrical wires each of radius a, and if the distance between their axes be c, the voltage E at which the corona appears is given by

$$[illegible]$$

very approximately.

F. W. Peek has found that the corona loss P in watts [illegible]

$$P = [illegible]\,(E - E_0)^2,$$

where E is the [illegible] between the mains and E_0 is the value of this pressure when the corona first appears. Any roughness on the surface of the wires naturally lowers the value of E_0. When the corona appears with continuous-current supply, the negative wire is covered with reddish tufts and the positive wire is surrounded by a bluish white glow having a needle-like fringe and interspersed with reddish tufts of light.

10. VORTICES.

The motion of a whirlpool or a whirlwind is an example of a simple vortical column with two ends. A smoke ring is an example of a circular vortex closed on itself. The analogy between the motion of vortex rings in a liquid or gas and the magnetic forces due to an electric current flowing in a ring or to the magnetic forces due to a small magnet was perceived by Thomson as early as 1850. But it was not until Helmholtz published in 1858 his classical paper on the dynamical laws of vortex motion that Thomson fully appreciated this analogy. Mathematically speaking, the problem of finding the velocity at any point of an incompressible fluid near a vortex filament is the same as that of finding the magnetic force near a filament carrying an electric current. The strength m of the vortex corresponds to the strength i of the current, and the fluid velocity corresponds to the magnetic force. If r be the radius of the cross-section of a vortex ring and ω be the angular velocity of points on the ring round the circular axis, the strength m of the vortex is $\pi r^2 \omega$. In the electrical problem the magnetic force tangential to the ring is $2i/r$, and in the hydrodynamical problem the corresponding velocity is ωr. Hence to convert the formulæ for the magnetic force at a point into the corresponding formulæ for the fluid velocity at that point we must multiply by $\omega r^2/(2i)$, that is, by $m/(2\pi i)$.

The magnetic force at any point in the neighbourhood of a circular electric current can be written down easily in terms of elliptic functions.* Hence the velocity at a point P in a fluid near a vortex ring can be found at once. For instance, the velocity of the fluid at the centre of the vortex ring is $(2\pi i/a)(m/2\pi i)$, that is, m/a where a is the radius of the axis of the ring. It also follows from the geometrical construction for the magnetic force (*loc. cit. ante*) that points on the surface of the ring have a velocity $m/\pi r$, that is, ωr about the circular axis and a linear velocity w in the direction of the axis where

$$w = \frac{m}{2\pi a}\left(\log_e \frac{8a}{r} - 1\right)$$

In an Appendix to P. G. Tait's translation of Helmholtz's Memoir on Vortex Motion (*Philosophical Magazine*, 1867, vol. 33, p. 511) Thomson gives without proof that

$$w = \frac{m}{2\pi a}\left(\log_e \frac{8a}{r} - \frac{1}{4}\right)$$

This is also the value given in Lamb's "Hydrodynamics."

If T_1 be the kinetic energy of the moving fluid and R the resultant magnetic force at a point ∂v in the electrical problem, we have

$$T_1 = \tfrac{1}{2}\rho\,\Sigma\,(u^2 + w^2)\,\partial v = \frac{\rho m^2}{8\pi^2 i^2}\,\Sigma\,(X^2 + Y^2 + Z^2)\,\partial v,$$

where ρ is the density of the fluid, u and w the component velocities at right angles and parallel to the axis of the filament respectively, and X and Z are the corresponding component magnetic forces. Hence

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* A. Russell, "Alternating Currents," [illegible]

$$\mathrm{T}_1 = \frac{\rho m^2}{\pi i^2} \sum \left(\frac{\mathrm{R}^2}{8\pi}\right) \partial v = \frac{\rho m^2}{2\pi} \mathrm{L}_1,$$

where $\mathrm{L}_1 (\frac{1}{2} i^2)$ is the energy due to the linkages of the lines of induction with the whole of the current. Hence

$$\mathrm{T}_1 = 2 \rho m^2 a [\log (8 a/r - 2].$$

Let us now suppose that the core of the vortex ring is solid so that the angular velocity of every point in it round the circular axis is constant. This corresponds to assuming that the current density over the cross-section of the ring in the corresponding electrical problem is constant. If we also suppose that the density of the core is the same as that of the fluid, the kinetic energy T_2 of the core will be given by

$$\mathrm{T}_2 = \tfrac{1}{2} \rho \pi r^2 2 \pi a \{ (\tfrac{1}{2} r^2) \omega^2 + u^2$$

$$= \tfrac{1}{2} \rho m^2 a + \text{small terms.}$$

Hence we get for the total kinetic energy T of the vortex ring and of the moving fluid in its neighbourhood

$$\mathrm{T} = \mathrm{T}_1 + \mathrm{T}_2 = 2 \rho m^2 a \{\log (8 a/r) - 1{\cdot}75\} = (\rho m^2/2\pi) \mathrm{L},$$

where L is the self-inductance of the circular current. This agrees with the formula given in Lamb's "Hydrodynamics" (3rd Ed., p. 227).

The ultimate nature of matter was a problem which strongly attracted Thomson, and he made many speculations concerning it. In his class he taught the atomic theory of gases, but he regarded the infinitely rigid atom of Lucretius as a monstrous and totally untenable assumption. Stokes's theory explaining the phenomena of spectrum analysis requires that the ultimate molecules which form a body must have one or more periods of vibration. To assume such a property in the Lucretian atom is to give it that very flexibility and elasticity which it is supposed to explain. Now vortices once started in a perfect fluid will exist for ever. They have perfectly definite periods of vibration, and their period is the same now as when they were created. May not the constitution of matter be explained by a vortex atom theory? One of his suggestions was that the sodium atom might consist of two vortex atoms looped together like links in a chain. Ultimately, however, the theory became so complex that he was reluctantly compelled to abandon it.

II. THE DIFFUSION OF HEAT.

In the session 1881–82, Sir William Thomson lectured to his senior mathematical class on the theory of the conduction of heat. He discussed Fourier's theorem, the equations to the flow of heat, the method of images, the propagation of summer heat downwards into the earth, and the diffusion of heat. As there were many demands made on the professor's time at this period, one or two of the lectures he gave us were unfinished. In particular the lecture on the "rate of diffusion" seems to have ended somewhat abruptly. As the problem is of great physical interest, it will be useful to give a brief abstract of the lecture and carry the theory a little further than Thomson did.

If we suppose that a quantity q of heat is communicated to a point O in an infinite homogeneous solid, initially at the temperature zero, then the temperature θ at any point distant r from O, at the time t, was proved by Fourier to be given by

$$\theta = \frac{q}{[2 \sqrt{(\pi \kappa t)}]^3} \varepsilon^{-r^2/(4\kappa t)},$$

where κ is the diffusivity of the medium, *i.e.* the ratio of the conductivity to the specific heat. For a given value of r, θ has its maximum value when $t = r^2/(6\kappa)$. Let us now consider the velocity $(\partial r/\partial t)$ of the spherical isothermal surface which at any instant passes through all the points which have their maximum temperature at this instant. The velocity of this surface is $(1{\cdot}5\,\kappa/t)^{\frac{1}{2}}$. We may therefore say, as Thomson did, that the rate of the diffusion varies directly as the square root of the diffusivity and inversely as the square root of the time. In the case of material diffusion the surface Thomson chose as specifying the rate of the diffusion is the surface which brings to each point its maximum density. He pointed out that the error function was most useful when discussing these problems, and he set the class the problem of finding the envelope of the curves connecting θ and r by eliminating the variable parameter t. The result, we were told, is the curve of maximum temperature.

Instead of considering the motion of the surface, which brings to each point its maximum temperature, we might consider the surface which passes through the points where the flow of heat is a maximum. If F denote the flow of heat, we have

$$\mathrm{F} = -k\,4\pi r^2 \frac{\partial \theta}{\partial r} = \frac{q r^3}{4\sqrt{(\pi \kappa^3 t^5)}} \varepsilon^{-r^2/(4\kappa t)}.$$

If t is constant F has its maximum value when $r^2 = 6\kappa t$, that is, $t = r^2/6\kappa$. Hence at any given instant the flow is greatest across the isothermal surface passing through the points which attain their maximum temperatures at this instant.

If, however, we suppose that r is a constant the flow attains its maximum value when $t = r^2/10\,\kappa$.

Let us now consider the fraction of the total heat contained inside a sphere of radius r at the time t, the centre of the sphere being at the origin. If this quantity of heat be αq, we have

$$\alpha q = \int_0^r 4\pi r^2 \theta\, \partial r = \frac{2q}{\sqrt{\pi}} \int_0^\beta \varepsilon^{-x^2} \partial x - \frac{\beta q}{\sqrt{\pi}} \varepsilon^{-\beta^2},$$

and therefore $\alpha = (2/\sqrt{\pi}) \operatorname{erf} (\beta) - (\beta/\sqrt{\pi}) \varepsilon^{-\beta^2}$,

where $\beta^2 = r^2/(4\kappa t)$ and erf (β) is Glaisher's notation for the error function. The values of $(2/\sqrt{\pi}) \operatorname{erf} (\beta)$ are tabulated in Dale's "Mathematical Tables." We see at once from this equation that if β is constant α is constant. It therefore follows that all the families of spheres obtained by giving various values to β include a constant quantity of heat, and any one of them might be taken as the surface which specifies the rate of the diffusion.

We see, for instance, that the spherical isothermal surface which contains about six-tenths (0·6087) of the total heat moves with a velocity $1{\cdot}23\,(\kappa/t)^{\frac{1}{2}}$ and brings to each point of the solid its maximum temperature. The spherical isothermal surface which expands with velocity

1·58 (κ t)½ contains about nine-tenths of the total heat given to the solid, and the flow of heat out of the fixed spherical surface with which it coincides at any instant has its maximum value. The motion of either of these surfaces, therefore, might conveniently be taken to define the rate [illegible]

[illegible] a point, and the velocity with which the heat is communicated to distant points is apparently infinite at the beginning of the motion. Fourier appreciated the first difficulty, and the second is explained by Maxwell in his "Theory of Heat."

The theory can be made more applicable to physical [illegible] material with its centre at the origin and initially at temperature θ_0, the temperature of the rest of the material being zero. It is easy to show by means of the formula given by Thomson for a constant spherical surface source ("Collected Papers," vol. 2, p. 45) that if a be the radius of the sphere, then θ the temperature at any point of the solid at a distance r from the origin at the time t is given by

$$\theta = [illegible]$$

It readily follows that θ has its maximum value when

$$\frac{a r}{a^2 + 2\kappa t} = \tanh \frac{a r}{2\kappa t} \quad . \quad . \quad . \quad (a)$$

[illegible] we find as formerly that $t = r^2/(6\kappa)$.

We also have

$$F = -k \frac{\partial \theta}{\partial r} = [illegible]$$

[illegible]

Differentiating F with regard to r and equating to zero we get equation (a). Hence at a given instant the flow is a maximum across the points which are at the highest [illegible]

[illegible]

$$F = [illegible]$$

[illegible] the same as for the ideal Fourier point [illegible]

[illegible] THE COOLING EFFECT PRODUCED BY A COVERING.

[illegible] was published, but a letter from J. T. Bottomley printed [illegible] of the paper. Thomson showed that if a body be below a certain size the effect of clothing may be to cool it. In particular he stated that for a globular body if the radius be less than $2k/e$, where k is the conductivity of the covering medium and e the emissivity, the temperature will be diminished by increasing the thickness of the covering until it equals $2k/e$. It will then be increased for greater thicknesses of the covering. Thomson knew the experimental result. He also knew that Fourier's assumption that e is constant is not legitimate. He therefore doubtless intended to rewrite the paper. A more accurate solution giving the same general result has been published by the author in the *Journal I.E.E.*, 1911, vol. 47, p. 744.

The corresponding problem for an insulated cylindrical wire placed in a cooling medium flowing transversely against it with velocity V is of importance in power transmission. Let a be the radius of the wire and b the outer radius of the insulating covering. Then if k be the conductivity of the cooling medium, s its specific heat, and σ its density, we have by Boussinesq's formula

$$c = \frac{4}{\pi}\sqrt{\left(\frac{s\sigma k V}{\pi a}\right)}$$

If k_1 be the conductivity of the covering, θ_1 the temperature of the wire, θ_0 the temperature of the outside of the covering, we have

$$\theta_1 - \theta_0 = \frac{H}{2\pi k_1} \log \frac{b}{a},$$

where H is the total quantity of heat emitted per unit length of the wire per second. Thus assuming that the cooling medium is initially at zero temperature we get

$$\theta_1 = \frac{H\sqrt{\pi}}{8\sqrt{(s\sigma k V b)}} + \frac{H}{2\pi k_1} \log \frac{b}{a}.$$

Let us now consider how θ_1 varies with $b - a$ when H and a remain constant. We have

$$\frac{\partial \theta_1}{\partial b} = \frac{H}{2\pi k_1 b}\left\{1 - \frac{\pi\sqrt{\pi}\, k_1}{8\sqrt{(s\sigma k V b)}}\right\}$$

Hence if a is less than $\pi^3 k_1^2/(64\, s\sigma k V)$, θ_1 diminishes as b increases, reaching a minimum value when $b = \pi^3 k_1^2/(64 s\sigma k V)$. Putting on a thin layer of insulating material, therefore, cools the wire in this case.

The following simple experiment illustrates this effect. Portions of a piece of thin manganin wire are insulated with glass, the rest being left bare. When placed in the air and heated electrically the bare pieces of wire glow brilliantly, but the portions covered by the glass are quite dark and are therefore at a much lower temperature.

It seems, therefore, that insulating overhead transmission wires with a suitable material would not only prevent the losses due to the formation of a corona but would allow more power to be transmitted without overheating the wires.

In the *Journal I.E.E.* [illegible] and James show that in certain cases their experiments prove that the fusing current of a wire varies as the 1·25th [illegible]

13. AGE OF THE EARTH AND SUN.

The age of the earth and the age of the sun were two problems to which Thomson devoted his best energies. It was undoubtedly a labour of love on his part. The "age of the earth" problem he had studied when a boy. He saw that the solutions given by Fourier would enable him to make an estimate provided that the average thermal diffusivity of the earth's crust were known. He and P. G. Tait carried out researches at Craigleith quarries near Edinburgh. From these data he made a rough estimate that it was about a hundred million years since the surface of the earth was molten. The discovery, however, that a small mass of radium can emit spontaneously an enormous quantity of heat has made it probable that his conclusion will have to be modified. It is possible also that a more accurate knowledge of the value of the diffusivity of the materials forming the earth, and especially of how the value of this diffusivity varies with the temperature, may appreciably alter the figure found by his method. The author remembers how in the session of 1881–82 Thomson discussed this point at length and quoted results obtained by several experimenters.

It has to be remembered, however, that Thomson did not base his conclusions on one method alone. The present shape of the earth, flattened at the poles, and protuberant at the equator, enables us to deduce its velocity of rotation just before it solidified. It is known that the tides act as a brake on the earth, making it rotate round its axis more slowly and thus lengthening the day. From a close study of the best astronomical data Thomson calculated that in a century the earth would lose about 20 seconds as compared with a perfect chronometer. A hundred million years ago the centrifugal force would be about three per cent greater than at present, and it can be shown that a liquid globe of attracting matter rotating at this speed would assume a shape which is approximately the same as the shape of the earth. This argument is of course quite unaffected by the presence of radio-active elements in the earth. Unfortunately, our knowledge of the processes of disintegration which occur in these elements is too slight and our ignorance of their distribution throughout the substance of the earth too profound to enable us to try and amend Thomson's estimate based on geothermic surveys. Thomson's estimate also of the age of the sun has to be amended as doubtless the sun is a great field of radio-activity. Rutherford and Soddy have pointed out that its heat could be maintained constant in this way over vast periods of time.

In his later years Kelvin was strongly attracted by the mystery of radium. Curie's astounding discovery that it emitted heat at the rate of about 90 calories per gramme per hour seemed to him explainable only on the theory that the energy of the radium was supplied by ethereal waves from outside. He gave as an illustration the case of a piece of cloth hermetically sealed in a glass vessel surrounded by water and exposed to the sun's rays. We know that the water will be perceptibly hotter when the cloth is black than when it is white. The energy travels into the black cloth by rays of sunlight and outwards through the same space by thermal conduction. The idea that the energy could arise by a change in the atom seemed to him incredible.

14. HIGH-FREQUENCY RESISTANCE.

In his presidential address to the Institution in 1889,* Thomson explained the variation in the density of a high-frequency current in a cylindrical conductor over its cross-section. He supposed that the conductor was either at a great distance away from the conductor for the return current, or that it was the inner conductor of a concentric main. He points out that at very high frequencies the current is practically confined to the surface of the conductor. This result might have been deduced from Willoughby Smith's experiments on the screening effect of metals. He gives a formula for the effective resistance of the conductor and also a table calculated by Magnus Maclean of the numerical values of the functions in terms of which the solution is expressed. Oliver Heaviside in discussing a similar problem previously had used two functions M and N which can be defined in terms of Bessel's functions by the equation

$$I_0(x\sqrt{\iota}) = M + \iota N.$$

Thomson called the functions M and N, ber x and bei x respectively on the analogy of the trigonometrical functions. Professor Andrew Gray has reminded me that ber is a contraction for "Bessel real" and bei is a contraction for "Bessel imaginary." It is to be noticed that

$$J_0(x\sqrt{\iota}) = \mathrm{ber}\, x - \iota\, \mathrm{bei}\, x.$$

These functions have now been tabulated to 9 significant figures (*B.A. Report*, 1912, p. 57). In other physical problems they have also been found useful.

In 1909 the author discussed the problem of the high-frequency resistance and inductance of a concentric main on the lines laid down by Thomson. In these solutions (imitating Thomson) he introduced two new functions which he called the ker and the kei functions. They are defined by the equation

$$K_0(x\sqrt{\iota}) = \mathrm{ker}\, x + \iota\, \mathrm{kei}\, x.$$

In Appendix 7 the solution of the problem is published for the first time in terms of these functions. As the numerical values of the ker and kei functions have been tabulated (*B.A. Report*, 1915, p. 36), the complete solution of the problem on the given assumptions has now been found.

It has to be remembered that in getting these solutions we have neglected the effects of capacity. No one appreciated this better than Thomson. The ordinary theory also neglects the energy lost by electrical radiation.

If we adopt the electron theory of electricity we must suppose that the kinetic energy of a current consists not only of the magnetic energy but also of the kinetic energy of the moving electrons themselves which compose the current. In the ordinary notation, therefore, the real kinetic energy equals

$$\tfrac{1}{2} L i^2 + \tfrac{1}{2} \Sigma m v^2,$$

where m is the mass of the electron and v its average forward velocity in the direction of the current. In most cases the correcting term can be neglected.

15. ELECTRICAL ENGINEER.

About 1870 telegraphists discussed the desirability of founding a society of telegraph engineers, and many it would naturally be expected to have Sir William Thomson as the first President (see Appendix [illegible]). As a matter of fact the initiative seems to have been taken by Colonel Sir Francis Bolton, General Webber, Sir William Siemens, and Colonel Malcolm [illegible]. In 1872 Sir William Siemens was the first President and it was not until 1874 that Sir William Thomson became President: Lord Lindsay, who was afterwards the Earl of Crawford and Balcarres, being one of the Vice-Presidents.

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* *Journal I.E.E.*, 1889, vol. 18, p. 4.

In 1877, when a juror at the Exhibition of Philadelphia, Thomson wrote a report on the exhibit of Gramme dynamos. He fully appreciated the enormous advance made by the abolition of permanent magnets. In 1878 he advocated the generation of electricity "in bulk." In 1879 he pointed out the suitability of the electric arc for street lighting and estimated its efficiency as 1·8 candles per watt. In 1881 he was most enthusiastic over the Faure accumulator, and his encouragement was a great help to the industry. This year he enunciated Thomson's law and pointed out the load at which the electrical efficiency of a shunt dynamo was a maximum. He also patented a special winding for an alternating-current dynamo. Ferranti independently invented an improvement of this design. They therefore entered into a working agreement and this association was influential in turning Thomson's attention to several of the problems which were then occupying the minds of engineers. In 1889 when the Society of Telegraph Engineers and Electricians changed its title to the Institution of Electrical Engineers, Thomson was again President. He was our President for the third time in 1907, the year of his death.

The wonderful series of electric measuring instruments which Thomson invented will always bear witness to his genius, his energy, and his inventive skill. Three of his ampere balances have been in use practically continuously at Faraday House for the last 27 years under ordinary commercial conditions. They are as accurate and useful now as when they were bought.

In 1881, Sir William Thomson and J. T. Bottomley communicated to the British Association the results of their tests on glow lamps. They measured the candle-power by a Harcourt's photometer and a standard candle, and the current and pressure by graded galvanometers. In addition they pointed out the necessity of determining the life of the lamp and how the candle-power diminishes with the blackening of the bulb. So far as the author is aware these are the first published tests of lamp efficiencies. The results are given in candles per horse-power. Horse-power was possibly adopted so that the efficiency would be expressed by a whole number, the greater this number the higher the efficiency—or it may have been adopted because the term "watt" was at that time too academic for the general public. The efficiencies of glow lamps are now expressed in "candles per watt," but for years they were always expressed in terms of the inefficiency of the lamp, that is, in "watts per candle."

In the photometry of new types of lamp the efficiency must be expressed in mean spherical candles per watt as the total light sent out by the lamp has to be measured. When one is engaged in testing the most [illegible] lamps interesting phenomena are noticed. For instance in certain lamps, when rotated, the candle-power continually increases with the speed of rotation. At [illegible] revolutions per minute the light may be about 15 per cent greater than when the lamp is stationary. At this speed also the current may be 1 or 2 per cent less than when the lamp is stationary although the voltage is maintained constant. The rotation, therefore, appreciably increases the efficiency. An explanation of this phenomenon may be given by considering the effects of the centrifugal force on the convection currents of gas inside the bulb and remembering that the resistance of the hot tungsten filament increases as its temperature increases.

16. THOMSON AS A TEACHER.

The author attended Sir William Thomson's Natural Philosophy class at Glasgow University in 1878–79 and his higher mathematical class during the sessions 1878–79 and 1881–82. In the Natural Philosophy class Thomson was a most inspiring teacher and showed many most interesting experiments. Those students, however, whose ambitions were limited to passing degree examinations got more help from Mr. Bottomley and Donald Macfarlane, his assistants.

In the higher mathematical class of 1878 Thomson started lecturing on simple cycloidal systems. As the new edition, vol. 1, part i, of Thomson and Tait's "Natural Philosophy" was then in the press, he was very busy correcting proof sheets and making additions. In fact most of the paragraphs numbered 345^1 to 345^{28} were given as part of the lectures. The author was sadly puzzled in trying to understand what a cycloidal system was. Thomson defined it as a system so constituted that the positional forces are proportional to displacements, the motional forces to velocities, and in which the kinetic energy is a quadratic function of the velocities with constant coefficients. Lagrange's equations of motion were then written down.

Although the author failed at the time to grasp the mathematical principles of the motions of gyrostats, yet he thoroughly enjoyed the lectures and seeing gyrostats swing so as to be "azimuthally stable, one inclinational mode unstable the other stable without rotation; with rotation two unstable, one stable." Professor Andrew Gray in the Sixth Kelvin lecture* showed some of these experiments. He also gave the theory in a form which can be readily grasped and gave several novel and valuable results.

Thomson was always so enthusiastic in these lectures, getting his class to work out mathematical theorems which some of them could do and giving them all kinds of interesting information. He told them, for instance, that once when showing a gyroscope to Helmholtz the wheel flew off and utterly demolished Helmholtz's new hat. He had therefore "to cage it in like a wild beast." It was necessary also to change its name and so he called it a gyrostat. The author left his class in 1879 badly fitted to pass examinations and with very hazy notions about the theory of gyrostats, gimbals, azimuthal motions, and Lagrange's equations, but with the highest admiration in every way for Sir William Thomson and an appreciation of the pleasures of original research. In particular he admired Thomson's way of never passing over difficulties.

During the session 1881–82 Sir William Thomson lectured on the theory of heat and gave the Fourier mathematics. The author finds by looking back at his notes that he quite understood all that was given. Thomson was very busy at this time with all manner of electrical experiments but he did not refer to them in this class.

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* *Journal I.E.E.*, vol. [illegible]

In solving problems the mathematical processes Thomson used nearly always had a physical significance. He solved problems in one branch of physics by methods suggested by other branches. For instance, he found the electric attractions of spheres by the optical method of images and obtained the solutions for the propagation of signals in a submarine cable by analogy with the problem of the diffusion of heat along a bar. He also solved many magnetic problems by analogy with the corresponding hydrodynamical problems. Much of his success was due to his ability to grasp quickly the analogy between problems in various branches of physics.

With pure mathematics he had little sympathy. He regarded it merely as a tool. He could not understand how to the pure mathematician the work of the physicist sometimes appears trivial. From the mathematical point of view the really important matter is to obtain the solution. The mathematician is little interested if a physicist at a later date applies his solution to explain some physical phenomenon. To Thomson this attitude of mind seemed a symptom of mental disease.

17. Conclusion.

In what precedes the author has only dealt with a few aspects of Lord Kelvin's life and work which are of general interest to engineers. He has not touched on the epoch-making advances Lord Kelvin made in the theory of thermodynamics or his wonderful researches in the theory of elasticity and the figure of the earth. Kelvin's name would be world-famous if he had written on one only of any of the following subjects—thermodynamics, electricity, magnetism, elasticity, telegraphy, heat, hydrodynamics, electrical engineering, mathematics, dynamics or navigation. His explorations in all of these subjects help us to realize the boundless unexplored fields of research which stretch before us in endless perspective. Had it not been for Kelvin the world would be perceptibly poorer to-day. His published works are a gift to universal humanity. As an imaginative thinker, a powerful reasoner, and a skilful inventor, Kelvin was probably unique. English electrical engineers will do well always to remember him gratefully. During the last few weeks of his life he often thought of our Institution with kindly affection. His work will endure and his

> "Life, like a dome of many-coloured glass,
> Stains the white radiance of Eternity."

APPENDIX.

1. Letter from Sir William Ramsay.

The following is an extract from a letter to the author by the late Sir William Ramsay, dated 2 June, 1912. Discussing Kelvin he writes:

"I knew him when I was a boy, for he and my father were fellow-students in James Thomson's class, and they always kept up their acquaintance. He was very good to me as a young lad; I was often asked to his house before his second marriage; and later, when Lady Thomson thought he was overdoing it, I used to be invited to make a fourth at whist; it was a little solemn and awkward, for he used to yawn, and evidently wished to be doing anything but playing whist.

"I had a spurious reputation as a student: I knew a fair amount of chemistry, and when I was in his class he used to put questions to me which I usually answered. They were questions in elementary chemistry; if he had tried me with questions such as he put to the more mathematically gifted, I should have been floored. Macfarlane could have told another tale about me; he knew how dense I was. However, I got a lot from Thomson; I still have the notes I took in his class; they are very decent, though I say it as shouldn't.

"Later on I worked in his laboratory at the 'New College.' He set me to do work with a quadrant electrometer; and after I had got the 'hang' of it I had an idea which pleased him much; it was to coat a penny rubber balloon with blacklead outside and inside, fill it with hydrogen and see if I could get a potential difference. I did; but no usable current. The notion was motive power for balloons. Nothing was ever published, but he ever after had an exaggerated idea of my capabilities."

2. An Approximate Formula for Electric Capacity.

If the capacity of a conductor be C and the charge on it be Q, the electrostatic energy of the isolated system is $Q^2/(2\,C)$. If therefore the shape of the surface alters in any way, the charge remaining constant, we see by the conservation of energy that the new capacity C′ is given by the equation

$$Q^2/(2\,C) - Q^2/(2\,C') = W,$$

where W is the total mechanical work done by the electric forces during the deformation. If the work W that has to be done by the electric forces in order to effect the new stable distribution of the electric charge be positive, C′ must be greater than C, but if it be negative, that is, if energy has on the whole to be communicated to the system, the capacity must be diminished. It is easy to see that the amount of work done by slightly deforming the surface of a conductor is very small compared with the total electric energy of the system. The alteration produced in the capacity of the conductor will therefore be small.

We know that the capacities of conductors of the same shape vary as the square root of their surfaces. Hence doubling the surface only increases the capacity by about 40 per cent, and halving it only diminishes the capacity by about 30 per cent. As the capacity of a conductor, therefore, varies slowly as compared with its surface and is, as a rule, not much affected by small changes in the shape of the conductor, an approximate formula connecting the two may be of value in practical work.

In the *Proceedings* of the Mathematico-Physical Society of Tōkyō, p. 243, January 1908, K. Aichi points out that the capacity of an ellipsoidal conductor is given very approximately by $(S/4\pi)^{\frac{1}{2}}$ where S is the surface of the ellipsoid. We shall first of all verify and extend his calculations and then consider whether the formula

$C =$ [illegible] $(S/4\pi)^{\frac{1}{2}},$

[illegible] unity, might not be usefully employed in order to obtain [illegible]

[illegible] arranged in descending order of magnitude, and if [illegible]

$$[illegible] \qquad (1)$$

$$[illegible] \qquad (2)$$

where F and E denote the elliptic integrals of the first and second order respectively. Their values are tabulated in [illegible]

From (1) we deduce the following instructive formula

$$[illegible] \qquad (3)$$

[illegible]

$$C = [illegible] \qquad (4)$$

Hence we deduce that

$$C = [illegible] \qquad (5)$$

Comparing (3) and (5) we see that when e_1 and e_2 are small, [illegible]

[illegible]

$$[illegible] \qquad (6)$$

When this is permissible, therefore, we see that if e_1 is [illegible] $(S/4\pi)^{\frac{1}{2}}$, but for all values of e_1 between these limits C is [illegible] than $(S/4\pi)^{\frac{1}{2}}$. For instance, e_2 is zero for a prolate [illegible] and therefore C is greater than $(S/4\pi)^{\frac{1}{2}}$, but for [illegible] $C = 1{\cdot}00174$, and for an oblate spheroid when $e_1 = e_2 = \frac{1}{2}$, [illegible]

If the greatest value of the eccentricity of any section of [illegible] than a half, the error made in [illegible]

[illegible]

in the second that α is 0·9848, and in the third that α is [illegible]. Although the shape of these conductors is very far from being spherical, yet the inaccuracy due to using the formula $C = (S/4\pi)^{\frac{1}{2}}$ is in all cases less than 2 per cent.

The following table* gives the value of α for two spheres each of radius a joined by a very fine wire, for various values of the distance c between their centres.

c/a	α	c/a	α	c/a	α
2·0001	[illegible]	2·6	1·028	6	1·213
2·01	[illegible]	2·7	1·047	7	1·238
2·1	[illegible]	2·8	1·055	8	1·257
2·2	[illegible]	2·9	[illegible]	9	1·273
2·3	1·010	3	1·071	10	[illegible]
2·4	[illegible]	4	1·135	100	1·400
2·5	[illegible]	5	[illegible]	1,000	1·413

Unequal spheres.—Let us now consider the case of the surface formed by two spheres whose radii are a and b respectively and intersecting orthogonally. In this case†

$$C = a + b - ab/(a^2 + b^2)^{\frac{1}{2}} = \alpha (S/4\pi)^{\frac{1}{2}},$$

and hence we compute the following values of α

b/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
α	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The case of two spheres‡ very close together and connected by a fine wire is interesting. Let the radii of the spheres be a and b respectively and let C_a and C_b denote their component capacities, and $C = C_a + C_b$ be their joint capacity. From the formulæ and tables given by the author (*loc. cit.*) the following table can be easily calculated.

[illegible]	[illegible]	[illegible]	[illegible]	α
1	[illegible]	[illegible]	[illegible]	[illegible]
2	0·4940	0·8516	1·0986	[illegible]
3	[illegible]	0·9126	[illegible]	[illegible]
4	[illegible]	0·9424	1·0200	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Elliptic plate.—If we put [illegible] we get

$$C = [illegible] \qquad (7)$$

[illegible]

$$C = [illegible]$$

When b is not less than 0·7 a, we can write

$$C = [illegible]$$

[illegible]

[illegible]

the maximum inaccuracy being about the fifth part of 1 per cent and occurring when $b = 0{\cdot}7\,a$. We see that as a/b increases C increases, its least value being $0{\cdot}9000\,a$. When $a = 3{\cdot}7\,b$, we have

$$C = 0{\cdot}9978\,(S/4\,\pi)^{\frac{1}{2}},$$

and when $a = 3{\cdot}8\,b$, we have

$$C = 1{\cdot}0027\,(S/4\,\pi)^{\frac{1}{2}}.$$

Thus when a is nearly equal to $3{\cdot}75\,b$ we have $C = (S/4\,\pi)^{\frac{1}{2}}$.

It is easy to see that for a very elongated elliptic plate or for a very elongated ellipsoid α can be very great. For instance, for a prolate spheroid, although when $a = 2\,b$, α is only 1·006, yet when $a = 10{,}000\,b$, α is nearly equal to 11·4.

Capacity of an anchor ring.—In the following table r denotes the radius of the cross-section of the ring and $R-r$ is the radius of its aperture. The values of C given have been computed by F. W. Dyson.*

R/r	C/R	$(S/4\pi)^{\frac{1}{2}}/R$	α
2	1·200	1·253	0·958
2·5	1·106	1·121	0·987
$3\frac{1}{3}$	0·9917	0·9709	1·021
5	0·8700	0·7928	1·097
10	0·7216	0·5606	1·284

We see that for values of R/r lying between 2 and 5 the capacity is given roughly by $(\pi\,r\,R)^{\frac{1}{2}}$, the maximum error being less than 10 per cent. When R/r is nearly equal to 2·8, the capacity is given by $(\pi\,r\,R)^{\frac{1}{2}}$ with high accuracy. For very large values of R/r the ordinary formula $\pi R/\{\log(8\,R/r)\}$ gives C accurately. In this case α is very great. This also follows since the electrostatic energy for a given charge is very small when R/r is great.

Spherical bowl.—As a final example let us consider Thomson's problem of the spherical bowl.† Let the radius of the bowl be a and let $2\,\theta$ be the angle which a diameter of its circular rim subtends at the centre of the sphere of which the bowl is a portion.

In this case

$$C = \frac{a}{\pi}(\theta + \sin\theta), \quad \text{and} \quad S = 4\,\pi\,a^2(1 - \cos\theta).$$

Therefore
$$C = \frac{\theta + \sin\theta}{\pi\sqrt{2}\sin(\theta/2)} \cdot \left(\frac{S}{4\,\pi}\right)^{\frac{1}{2}}.$$

Thus as θ increases from 0 to $\pi/2$, α diminishes from 0·9000 to 0·8183. In order to bend a circular plate so that it becomes part of a sphere, the charge remaining constant, we see that work has to be done, as the electrostatic energy has increased owing to the diminution of the capacity.

Finding the surface of conductors.—The formula $C = (S/4\pi)^{\frac{1}{2}}$ can also be applied in many cases to find a roughly approximate value of the surface of a conductor when the capacity has been found. For instance, the surface S formed by four spheres intersecting orthogonally, the radii of which are a_1, a_2, a_3, and a_4 respectively, is approximately equal to $4\,\pi\,C^2$, where C is given by *

$$C = \Sigma\,a_1 - \sum\frac{a_1\,a_2}{(a_1^2 + a_2^2)^{\frac{1}{2}}} + \sum\frac{a_1\,a_2\,a_3}{(a_1^2\,a_2^2 + \ldots)^{\frac{1}{2}}} - \frac{a_1\,a_2\,a_3\,a_4}{(a_1^2\,a_2^2\,a_3^2 + \ldots)^{\frac{1}{2}}}$$

The principal conclusions arrived at in this section may be summed up as follows :—

For an oblate spheroid the capacity is slightly less than $(S/4\,\pi)^{\frac{1}{2}}$.

For a prolate spheroid it is only slightly greater than $(S/4\,\pi)^{\frac{1}{2}}$ until the polar diameter gets much greater than the equatorial diameter.

Not only is the formula $C = (S/4\,\pi)^{\frac{1}{2}}$ exactly true for a sphere, but also for such differently shaped conductors as an anchor ring, the radius of the aperture of which is about 1·8 times the radius of its cross-section, an elliptic plate the ratio of the axes of which is about 3·75, and for two equal spheres connected by a fine wire when the distance between their centres is roughly equal to 2·2 times the radius of either.

It is suggested that the formula $C = (S/4\,\pi)^{\frac{1}{2}}$ might sometimes be useful when an approximate value of the capacity of a conductor is required.

3. THE FORCES BETWEEN INSULATED ELECTRIFIED CONDUCTORS.

If two insulated conductors A and B have charges q_1 and q_2 respectively, and if their dimensions are infinitely small compared with the distance r between them, we have

$$F = \frac{q_1\,q_2}{r^2}, \quad \ldots\ldots\ldots \quad \text{(i)}$$

where F the force between them is repulsive when q_1 and q_2 have the same sign, and attractive when they have opposite signs. This is Coulomb's law. When the dimensions of A and B are comparable with r, each element of electricity on either conductor attracts or repels all other elements of electricity according to Coulomb's law. In the position of equilibrium, therefore, the distribution of the charges on the conductors follows a complex law and the simple formula (i) no longer holds.

For instance, for finite bodies when q_2 is zero, the force between them is not zero as (i) indicates, but is attractive. A rough explanation of this may be given as follows :—

Let us suppose that A has a positive charge, then on the side of B adjacent to A a negative charge will be induced and an equal positive charge on the other side of B. The force between A and B will be the resultant of the attraction between the charge on A and the negative charge on B and of the repulsion of the A charge on the positive charge on B. As the negative charge on B is the nearer to A, the attractive force will be the greater, and hence the resultant force will be attractive. It is easy to see also that if the distance between the two conductors is fixed and we gradually communicate a positive charge to B the force between them gradually changes from attraction to repulsion passing through the value zero.

Thomson obtained the complete mathematical solution

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* *Philosophical Transactions of the Royal Society*, A, 1893, vol. 184. Part I, p. 43.

† W. THOMSON: "Reprint," p. 178. N. M. FERRERS: *Quarterly Journal*, vol. 18, p. 97.

* C. MAXWELL: "Electricity and Magnetism," vol. 1, § 169.

[illegible] The [illegible] can now be easily calculated in all cases.*

If v_1 and v_2 be the potentials of any two conductors which have charges q_1 and q_2, we have

$$[illegible] \quad \text{and} \quad [illegible]$$

where [illegible] are coefficients the values of which depend only on the shape and the distance apart of the two conductors. The energy W stored up in the electrostatic field is given by

$$W = \tfrac{1}{2} q_1 v_1 + \tfrac{1}{2} q_2 v_2$$

and so $$W = \tfrac{1}{2} p_{11} q_1^2 + p_{12} q_1 q_2 + \tfrac{1}{2} p_{22} q_2^2 \quad . \quad . \quad . \quad \text{(ii)}$$

If q_2 be kept constant it is easy to see from (ii) that W has its minimum value when v_1 is zero. Similarly if v_2 be variable and v_1 be kept constant, W has its minimum value when q_2 is zero. If we have two spheres whose radii are a and b and if c be the distance between their centres, we have

$$p_{11} = \frac{1}{a} - \frac{b^3}{c^4}, \quad p_{12} = \frac{1}{c} \quad \text{and} \quad p_{22} = \frac{1}{b} - \frac{a^3}{c^4}$$

when small quantities of the order $(a/c)^6$ or $(b/c)^6$ can be neglected compared with unity.

For example, if $c = 4a = 4b$, we have

$$p_{11} = [illegible](1/a) = p_{22} \quad \text{and} \quad p_{12} = 0{\cdot}25000(1/a).$$

The true values given by Thomson are

$$p_{11} = [illegible]583(1/a) = p_{22} \quad \text{and} \quad p_{12} = 0{\cdot}25015(1/a).$$

Hence for values of c/a not less than 4 the accuracy of the approximate formulæ is quite satisfactory.

If the spheres are electrified the resultant force F between them will, from symmetry, be in the direction of the line joining their centres. If the charges q_1 and q_2 on the spheres remain constant, we obviously have, by the principle of the conservation of energy, that $F\,\partial c = -\,\partial W$, where F is the repulsive force between the spheres. Hence

$$F = \frac{q_1 q_2}{c^2} - \frac{2b^3}{c^5} q_1^2 - \frac{2a^3}{c^5} q_2^2 \quad . \quad . \quad . \quad \text{(iii)}$$

is the approximate formula for the repulsive force between two spheres.

If q_1 and q_2 are equal and have the same sign the formula (i) makes the repulsive force too great, but if they have opposite signs it makes the attractive force too small.

In the particular cases when

$$[illegible] \quad . \quad . \quad \text{(iv)}$$

the value of F vanishes and the spheres are in neutral [illegible].

Let us consider, for instance, the case when the distance between the spheres equals the diameter of either. In [illegible]

[illegible] we get

$$F = [illegible]$$

From Thomson's figures we find that the accurate formula is

$$F = [illegible]$$

We see that in this case the error in using the formula $F = q_1 q_2/c^2$ is least when $q_1 = q_2$. It is then greater than 6 per cent.

We also find from (iv) that F vanishes when q_1/q_2 is either 0·031 or 32 approximately. Thomson gives the true numerical values which are 0·03444 and 29·04. Hence formulæ (iii) and (iv) are only roughly approximate when c/a is as small as 4. The example illustrates the kind of analytical work by means of which Thomson obtained the exact solution of the problem. Snow Harris in his "Rudimentary Electricity" published in 1848 rightly says that this problem is one "which has hitherto greatly perplexed philosophers and mathematicians."

More general theorems are given in Russell's "Alternating Currents," vol. 1, 2nd Ed., pp. 150, 235 *et seq.*

4. ROBERT MURPHY.

Robert Murphy (1806–43) was the third of the seven children of a shoemaker who was parish clerk of Mallow, Co. Cork. When 11 years of age he was run over by a cart, and for 12 months lay in bed with a fractured thigh-bone. During this time he studied algebra and Euclid and became extraordinarily proficient at mathematics. His friends raised a subscription for him and he entered Gonville and Caius College, Cambridge, in 1825. He was third wrangler in 1829, and in 1831 was appointed Dean of the College. Shortly afterwards he had to leave Cambridge, his fellowship being sequestrated for the benefit of his creditors. In 1833 his "Electricity" was published. The book proves that he was a mathematician of a very high order. The physical side of electricity is barely considered. At this period apparently it was customary to discharge a Leyden jar through your body. Murphy says that a smart shock will be immediately felt.

5. GEORGE GREEN.

George Green (1793–1841) was born at Sneinton in Yorkshire, being the son of a miller who had private means. He was an entirely self-educated mathematician. His celebrated and important essay was published by subscription in 1828 at Nottingham, when he was 35 years old. At the age of 40 he entered Gonville and Caius College as a freshman and graduated as fourth wrangler in 1835. He was undoubtedly a physicist and mathematician of the highest order, but like Murphy he seems to have lacked ballast in the ordinary affairs of life.

6. JOHN KERR.

John Kerr (1824–1907) was born at Ardrossan, Ayrshire, and received part of his education at a parish school in Skye. He distinguished himself at Glasgow University, graduating with first-class honours in Mathematics and Natural Philosophy. He was ordained a minister of the Free Church of Scotland, and for 44 years lectured in the Free Church (now the United Free Church) Normal Training College for Teachers in Glasgow. Although he had very few laboratory facilities, yet he discovered the birefringence caused in glass and other insulators when placed in an intense magnetic field. He also discovered the change produced in polarized light when it is reflected from the polished pole of an electromagnet.

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* [illegible]

* [illegible]

7. HIGH-FREQUENCY RESISTANCE AND INDUCTANCE.

The problem of the high-frequency resistance and inductance of a concentric main is discussed in Russell's "Alternating Currents," vol. I, chap. 7, 2nd Ed. The final formulæ for R and L contain quantities A, B, C, and D, which have to be determined from four simple simultaneous equations. Mathematically the solution is complete, but in practice the numerical evaluation of the formulæ is laborious. The recent publication, however, in the *British Association Report*, 1915, of complete tables of the ker, kei, ker′, kei′ functions calculated to six significant figures for ranges of the argument from 0 to 10, at intervals of 0·1, has induced the author to solve the problem completely. He is indebted to Harold Savidge for pointing out to him that it follows from the general properties of Bessel functions that the ber and the bei functions are connected with the ker and the kei functions by certain simple relations. This has enabled him to simplify the solutions still further. A proof will first be given of the mathematical theorems which are used.

By definition it follows that $\mathrm{ber}\,x + \iota\,\mathrm{bei}\,x$ and $\mathrm{ker}\,x + \iota\,\mathrm{kei}\,x$ are both solutions of the equation

$$\frac{\partial^2 y}{\partial x^2} + \frac{1}{x}\frac{\partial y}{\partial x} = \iota\, y.$$

We get by substituting these values for y and equating the real and imaginary terms on each side of the equation that

$$\mathrm{ber}'\,x = - x\,\mathrm{bei}\,x - x\,\mathrm{ber}''\,x,\quad \mathrm{ker}'\,x = - x\,\mathrm{kei}\,x - x\,\mathrm{ker}''\,x,$$

and $\mathrm{bei}'\,x = x\,\mathrm{ber}\,x - x\,\mathrm{bei}''\,x$, $\mathrm{kei}'\,x = x\,\mathrm{ker}\,x - x\,\mathrm{kei}''\,x$.

If we write

$$y = \mathrm{ber}\,x\,\mathrm{ker}'\,x - \mathrm{bei}\,x\,\mathrm{kei}'\,x - \mathrm{ker}\,x\,\mathrm{ber}'\,x + \mathrm{kei}\,x\,\mathrm{bei}'\,x,$$

we get, by substituting for $\mathrm{ker}'\,x$, $\mathrm{kei}'\,x$, $\mathrm{ber}'\,x$, and $\mathrm{bei}'\,x$ their values given above, that

$$\begin{aligned} y &= x(-\mathrm{ber}\,x\,\mathrm{ker}''\,x + \mathrm{bei}\,x\,\mathrm{kei}''\,x + \mathrm{ker}\,x\,\mathrm{ber}''\,x \\ &\qquad - \mathrm{kei}\,x\,\mathrm{bei}''\,x) \\ &= -x(\partial y/\partial x). \end{aligned}$$

The solution of this equation is $y = a/x$, where a is a constant. Putting x equal to a very small number, we see from the series formulæ defining the functions that $y = -1/x$ in this case, and hence $a = -1$. Thus

$$\begin{aligned} \mathrm{ber}\,x\,\mathrm{ker}'\,x - \mathrm{bei}\,x\,\mathrm{kei}'\,x - \mathrm{ker}\,x\,\mathrm{ber}'\,x \\ + \mathrm{kei}\,x\,\mathrm{bei}'\,x = -1/x \end{aligned} \quad . \quad (1)$$

and similarly we find that

$$\begin{aligned} \mathrm{ber}\,x\,\mathrm{kei}'\,x + \mathrm{bei}\,x\,\mathrm{ker}'\,x - \mathrm{ker}\,x\,\mathrm{bei}'\,x \\ - \mathrm{kei}\,x\,\mathrm{ber}'\,x = 0 \end{aligned} \quad . \quad (2)$$

Let us first suppose that the inner conductor is solid and that its radius is a and that the inner and outer radius of the outer conductor are b and c respectively. Then solving equations (80), (81), (84), and (85), *loc. cit. ante* and substituting in formulæ (92) and (93) we get finally, after laborious algebraical operations, that

$$\begin{aligned} R &= \frac{\rho m}{2\pi a} \cdot \frac{W(ma)}{V(ma)} \\ &\quad + \frac{\rho m}{2\pi b\,\Delta(b,c)}\Big\{2\,S(mc)\,.\,(\mathrm{ber}\,mb\,\mathrm{kei}'\,mb - \mathrm{kei}\,mb\,\mathrm{ber}'\,mb) \\ &\quad\quad + 2\,T(mc)\,.\,(\mathrm{ber}\,mb\,\mathrm{ker}'\,mb - \mathrm{ker}\,mb\,\mathrm{ber}'\,mb) \\ &\quad\quad\quad + \frac{T(mc)}{mb} - V_1(mc)\,.\,W(mb) - V(mc)\,.\,W_1(mb)\Big\} \end{aligned} \quad . \quad (3)$$

and

$$\begin{aligned} L &= 2\mu' \log\frac{b}{a} + \frac{2\mu Z(ma)}{ma V(ma)} \\ &\quad + \frac{2\mu}{mb\,\Delta(b,c)}\Big\{2S(mc)\,.\,(\mathrm{ker}\,mb\,\mathrm{ber}'\,mb + \mathrm{bei}\,mb\,\mathrm{kei}'\,mb) \\ &\quad\quad + 2T(mc)\,.\,(\mathrm{ker}\,mb\,\mathrm{bei}'\,mb - \mathrm{ber}\,mb\,\mathrm{kei}'\,mb) \\ &\quad\quad\quad - \frac{S(mc)}{mb} - V_1(mc)\,.\,Z(mb) - V(mc)\,.\,Z_1(mb)\Big\} \end{aligned} \quad . \quad (4)$$

In these formulæ ρ is the resistivity of the metal, μ its permeability, and μ' the permeability of the insulating material separating the two conductors. The frequency of the alternating current is $\omega/2\pi$ and $m^2 = 4\pi\mu\omega/\rho$.

The functions are defined as follows:

$$\begin{aligned} S(x) &= \mathrm{ber}'\,x\,\mathrm{ker}'\,x + \mathrm{bei}'\,x\,\mathrm{kei}'\,x, \\ T(x) &= \mathrm{bei}'\,x\,\mathrm{ker}'\,x - \mathrm{ber}'\,x\,\mathrm{kei}'\,x, \end{aligned}$$

$$\begin{aligned} V(x) &= \mathrm{ber}'^2\,x + \mathrm{bei}'^2\,x, \\ V_1(x) &= \mathrm{ker}'^2\,x + \mathrm{kei}'^2\,x, \end{aligned}$$

$$\begin{aligned} W(x) &= \mathrm{ber}\,x\,\mathrm{bei}'\,x - \mathrm{bei}\,x\,\mathrm{ber}'\,x, \\ W_1(x) &= \mathrm{ker}\,x\,\mathrm{kei}'\,x - \mathrm{kei}\,x\,\mathrm{ker}'\,x, \end{aligned}$$

$$\begin{aligned} Z(x) &= \mathrm{ber}\,x\,\mathrm{ber}'\,x + \mathrm{bei}\,x\,\mathrm{bei}'\,x, \\ Z_1(x) &= \mathrm{ker}\,x\,\mathrm{ker}'\,x + \mathrm{kei}\,x\,\mathrm{kei}'\,x, \end{aligned}$$

$$\begin{aligned} \Delta(b,c) &= V_1(mc)\,.\,V(mb) + V(mc)\,.\,V_1(mb) \\ &\quad - 2\,S(mb)\,.\,S(mc) - 2\,T(mb)\,.\,T(mc). \end{aligned}$$

When mc is not greater than 2, (3) simplifies to

$$\begin{aligned} R &= \frac{\rho}{\pi a^2}\left(1 + \frac{m^4 a^4}{192}\right) \\ &\quad + \frac{\rho}{\pi(c^2 - b^2)}\left\{1 + m^4(\sigma + \sigma_1\xi + \sigma_2\xi^2)\right\} \text{ approximately,} \end{aligned} \quad (5)$$

where $\sigma = \dfrac{(7c^2 - b^2)(c^2 - b^2)}{192}$, $\sigma_1 = \dfrac{b^2 c^4}{8(c^2 - b^2)}$,

$\sigma_2 = -\dfrac{b^2 c^6}{4(c^2 - b^2)^2}$, and $\xi = \log\dfrac{c}{b}$.

We find in a similar way that in this case (4) simplifies to

$$\begin{aligned} L &= 2\mu' \log\frac{b}{a} + \frac{\mu}{2} + \frac{2\mu c^4}{(c^2 - b^2)^2}\log\frac{c}{b} - \mu\,\frac{3c^2 - b^2}{2(c^2 - b^2)} \\ &\quad - \frac{\mu}{2}\cdot\frac{m^4 a^4}{192} - \mu(\tau + \tau_1\xi + \tau_2\xi^2 + \tau_3\xi^3)\,m^4 \text{ approx.} \end{aligned} \quad (6)$$

where
$$\begin{aligned} \tau &= \frac{19c^6 + 103c^4b^2 - 41c^2b^4 + 3b^6}{2^2\,.\,4^2\,.\,6^2\,(c^2 - b^2)}, \\ \tau_1 &= -\frac{14c^4b^2(2c^2 - b^2)}{2^2\,.\,4^2\,.\,3\,(c^2 - b^2)^2}, \\ \tau_2 &= -\frac{c^6b^4}{4(c^2 - b^2)^3}, \\ \tau_3 &= \frac{c^8b^4}{2(c^2 - b^2)^4}, \quad \text{and} \quad \xi = \log\frac{c}{b}. \end{aligned}$$

Formulæ (5) and (6) are in exact agreement with formulæ [illegible] and (7) given on pp. [illegible] and 221 (loc. cit. ante).

If 4 [illegible] — [illegible] is not greater than [illegible] and a one per cent accuracy suffices, we have

$$[illegible] = 1 - [illegible] \text{ approximately}$$

and (5) becomes

$$R = \frac{\rho}{\pi a^2}\left(1 + \frac{m^4 a^4}{192}\right)$$
$$+ [illegible]\left(1 + \frac{m^4 [illegible]}{45}\right) \text{ approximately} \quad (7)$$

Similarly when $m a$ is less than 2 and $(c - b)^4/10\,b^4$ can be neglected compared with unity, we have

$$L_0 = 2\mu \log\frac{b}{a} + \frac{\mu}{2} + \frac{2\mu}{3}\cdot\frac{c-b}{b}$$

where L_0 is the value of L with continuous currents, and

$$[illegible] = -\frac{1}{945}\left(\frac{c-b}{b}\right)^{[illegible]}.$$

Hence (6) becomes

$$L = 2\mu \log\frac{b}{a} + \frac{\mu}{2} - \frac{\mu}{[illegible]}\cdot\frac{m^4 a^4}{192} + \frac{2\mu}{3}\cdot\frac{c-b}{b}\left\{1 - \frac{m^4 (c-b)^4}{630}\right\}$$
approximately . . . (8)

When $m a$ is greater than (5), we may use the following formulæ

$$R = \frac{\rho m}{2\pi a}\left\{\frac{1}{\sqrt{2}} + \frac{1}{2 m a} + \frac{3}{8 m^2 a^2 \sqrt{2}}\right\}$$
$$+ [illegible] \quad (9)$$

$$\text{and } L = 2\mu \log\frac{b}{a} + \frac{2\mu}{m a}\left(\frac{1}{\sqrt{2}} - [illegible] - \frac{3}{8 m^3 a^3}\right)$$
$$+ [illegible] \quad (10)$$

In Russell's "Alternating Currents," vol. 1, p. 222, 2nd Ed., a method is indicated for getting the solution of the problem when the inner conductor is hollow. Assuming that the inner and outer radii of the inner conductor have lengths a_1 and a_2 respectively, the current density ι at any point in the inner conductor at a distance [illegible] is given by

$$\iota = \{A \operatorname{ber} m r + B \operatorname{bei} m r + C \operatorname{ker} m r + D \operatorname{kei} m r\} \cos \omega t$$
$$+ \{[illegible]\} \sin \omega t.$$

If we suppose that [illegible] when $r = a_2$, it is shown (loc. cit. ante) that the equations to determine the four constants are

$$[illegible]$$

[illegible]

written down by comparing them with (1) and (2). We get, at once, that

$$A = -m a_1 \operatorname{ker}' m a_1, \qquad B = m a_1 \operatorname{kei}' m a_1,$$
$$C = m a_1 \operatorname{ber}' m a_1, \qquad D = -m a_1 \operatorname{bei}' m a_1.$$

Hence the problem is solved immediately. If I denote the amplitude of the current density at a point distant r from the axis, then when $(r-a_1)/a_1$ is not greater than $\frac{1}{4}$ and $m r$ is not greater than 2, we have

$$I = \iota\left\{1 + \frac{m^4 (r - a_1)^4}{12}\right\} \quad . \quad . \quad . \quad . \quad (11)$$

Hence I increases as r increases.

It can also be shown that if R denote the effective resistance of a length l of the hollow conductor we have

$$R = \frac{\rho m l}{2\pi a_1 \Delta(a_1, a_2)}\Big[2 S(m a_2)$$
$$.(\operatorname{ber} m a_2 \operatorname{ker}' m a_1 - \operatorname{ker} m a_2 \operatorname{ber}' m a_1)$$
$$+ 2 T(m a_2).(\operatorname{bei} m a_2 \operatorname{kei}' m a_1 - \operatorname{kei} m a_2 \operatorname{bei}' m a_1)$$
$$+ \frac{T(m a_2)}{m a_2} - V_1(m a_1).W(m a_2) - V(m a_1).W_1(m a_2)\Big] \quad (12)$$

It will be seen that equation (12) could have been deduced from (3) by neglecting the first term in the equation for R and writing a_2 for b and a_1 for c.

Similarly we can show that the part L_1 of the self-inductance L due to linkages of magnetic lines within the hollow inner conductor is given by

$$L_1 = \frac{2\mu l}{m a_1 \Delta(a_1, a_2)}\Big[2 S(m a_2)$$
$$.(\operatorname{ker} m a_1 \operatorname{bei}' m a_2 + \operatorname{bei} m a_2 \operatorname{ker}' m a_1)$$
$$+ 2 T(m a_2).(\operatorname{kei} m a_1 \operatorname{ber} m a_2 - \operatorname{ber} m a_1 \operatorname{kei} m a_2)$$
$$- \frac{S(m a_2)}{m a_2} - V(m a_1).Z(m a_2) - V(m a_1).Z_1(m a_2)\Big] \quad (13)$$

The formula for the effective resistance of the outer conductor and for the linkages of the magnetic lines in the outer conductor can be written down at once from (3) and (4) as they are obviously the same whether the inner conductor is solid or hollow.

When $m c$ is not greater than 2 and $(a_2 - a_1)/a_2$ is not greater than $\frac{1}{4}$ we have

$$R = \frac{\rho l}{\pi (a_2^2 - a_1^2)}\left[1 + \frac{m^4 (a_2 - a_1)^4}{45}\right]$$
$$+ \frac{\rho l}{\pi ([illegible])}\left[1 + \frac{m^4 (c - b)^4}{45}\right] \quad (14)$$

If we have two parallel cylindrical hollow conductors, their inner and outer radii being (a_1, a_2) and (b_1, b_2) respectively, and if the distance c between their axes be sufficiently great so that the distribution of the current in the one is not affected by the current in the other, the resistance of the two in series is got by adding to the expression for R given by (12) a corresponding expression deduced from the first by writing b_1 and b_2 for a_1 and a_2 respectively.

Similarly to find the self-inductance L of the two in series we have to add to the value L_1 given in (13) a corresponding expression deduced from it by writing b_1 and b_2 for a_1 and a_2 respectively, and also a term

$$2\mu' l \log \left\{ d^2/(a_2 b_2) \right\}.$$

For solid conductors the formula for L is

$$L = 2\mu' l \log \frac{d^2}{a\,b} + \frac{2\mu l}{m\,b} \cdot \frac{Z\,(m\,b)}{V\,(m\,b)} + \frac{2\mu l}{m\,a} \cdot \frac{Z\,(m\,a)}{V\,(m\,a)}.$$

Tables of the values of $\frac{1}{x} \cdot \frac{Z\,(x)}{V\,(x)}$ and of m for copper wires at various frequencies are given on pp. 233 and 234 (*loc. cit. ante*).

8. THE FOUNDING OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

From 1868 onwards, the question of starting a Society of Telegraph Engineers was discussed by several engineers and physicists. In a letter to the author dated 12th June, 1912, the Earl of Crawford and Balcarres says:

"The first inception of the Society was in my old laboratory in a slum called Eaton-place (now swept away) lying between Green-street, Grosvenor-square, and Oxford-street. Cromwell and Alfred Varley were great friends of mine and were constantly with me there—I was working then on electromagnetism and storage batteries—and Cromwell Varley talked so much about getting up a society of telegraph engineers that we decided to get up one, and when all was in order William Thomson was asked to be the first President."

It was not, however, until 1874 that Sir William Thomson was President, with Lord Crawford or, as he then was, Lord Lindsay, as Vice-President. The first soirée of the Society was held in Lord Crawford's laboratory at 48 Greek-street, Soho.

Colonel Malcolm, R.E., C.B., of Poltalloch, has told the author that the final move in founding the Society was taken as follows:

When he was at Chatham in charge of the electrical education of the Royal Engineers, Captain (General) Webber, who was his cousin, called on him and discussed the question of starting the Society. He asked him to join, and said that Charles Siemens (Sir William Siemens) was favourable. When Major Malcolm agreed, he said, "That's capital!—now we are three and can form a Society."

Mr. William O. Smith, son of Willoughby Smith (President in 1883), tells the author that he always understood from his father that the idea of forming the Society originated with Captain Bolton (afterwards Colonel Sir Francis Bolton). Captain Bolton asked Captain Webber to assist him in the formation of the Society, and the two approached those people likely to be of use in bringing in members: Major Malcolm; C. W. Siemens; Professor Abel (afterwards Sir Frederick Abel); the Post Office Engineers; Willoughby Smith, and doubtless many others.

THE THEORY OF ARMATURE WINDINGS.

By S. P. SMITH, D.Sc., Associate Member.

([illegible] March, [illegible] October, [illegible].)

SUMMARY.

In this paper an attempt is made to outline the theory of armature windings in heteropolar machines (i.e. machines with alternate north and south poles).

Section 1.—Attention is drawn to the fundamental importance of the relation between the number of slots and the number of poles, and, by the aid of simple vector diagrams, the condition is established for obtaining a winding in which the sum of all the induced pressures is zero at any instant. If all the coils in such a winding are joined in series to form a closed winding, no internal current can circulate. Following this, the condition is found for obtaining a number of similar symmetrical polyphase systems in such a winding, this being essential when parallel circuits are needed, as in most commutator machines. A winding fulfilling these conditions is called symmetrical, and an extension of the argument reveals the relationship that must exist between the number of slots and the number of poles in a symmetrical 3-, 4-, or 6-phase winding. Table 1 shows the number of similar circuits it is possible to have with various numbers of poles.

Section 2.—This deals solely with single-layer windings. The arrangement of the coils for various symmetrical and hemisymmetrical polyphase windings is discussed. The effect of the number of slots on the number of similar parts in each phase is shown, and the means indicated for suppressing tooth effects.

Section 3.—The arrangement of open and closed double-layer windings is illustrated, and the methods of loading closed windings are compared. The connecting rules for lap and wave windings are deduced, and the restrictions examined for making these windings symmetrical. These results are given in Tables 2 and 3, along with the slottings possible for N-phase, lap and wave windings. These tables enable the designer to see at once the number of coil-sides per slot, the number of slots, and the number of phases possible in any symmetrical winding.

Lastly, it is shown how to find the points where a winding must be tapped or opened to [illegible], examples being given to illustrate the various cases.

The contents of the paper are subdivided as follows :—

1. Symmetrical windings.

(I) Condition for obtaining a closed winding.
(II) Conditions for obtaining a symmetrical winding.
(III) [illegible]
(IV) Conditions for obtaining a symmetrical N-phase winding.
(V) [illegible]

2. Single-layer windings.

(I) Arrangement of single-layer windings.
(II) [illegible]
    (a) Whole number of slots per pole.
    (b) Fractional number of slots per pole.
        (i) [illegible]
        (ii) [illegible]

3. Double-layer windings.

(I) Arrangement of double-layer windings.
    (a) Phase tappings off closed windings.
        (i) Polygon tappings.
        (ii) Diametral tappings.
    (b) Open double-layer windings.
(II) Connecting rules for closed windings.
    (a) Closing rule for lap windings.
    (b) Closing rule for wave windings.
(III) Conditions for obtaining symmetrical lap and windings.
    (a) Symmetrical lap windings.
    (b) Symmetrical wave windings.
(IV) Conditions for obtaining symmetrical N-phase, la wave windings.
    (a) Symmetrical N-phase lap windings.
    (b) Symmetrical N-phase wave windings.
        (i) Number of poles.
        (ii) Number of slots.
(V) Location of tappings and openings.
    (a) Tappings off symmetrical lap and wave wind
    (b) Opened wave windings.
    (c) Illustrative examples.
(VI) Wave windings with a whole number of slots per p

DEFINITIONS.

The following definitions may be found useful in re the paper :—

Symmetrical polyphase system.—A polyphase syste said to be symmetrical when all the pressures hav same amplitude and are equally displaced from one an in a period, i.e. when $\beta = 2\pi/N$, where N is the numb phases and β the angle between successive phases such a system the sum of the N pressures is equal to at any instant, so that the N phases can be joined in (mesh) without causing internal currents to flow.

Hemisymmetrical polyphase system.—A polyphase sy is called hemisymmetrical when all the pressures hav same amplitude and are displaced from one anothe 1/Nth of half a period. A hemisymmetrical, N p system is equivalent to a symmetrical 2N-phase syst

Phase-pitch.—The displacement between two succ phases of a polyphase system is called the phase The phase-pitch can be measured in any suitable [illegible] [illegible], or expressed as a numb [illegible]. When measured in radians angular phase-pitch is β.

Phase-spread.—The angle subtended in each pole by the group of coils allotted a phase is called the an phase-spread. This will be denoted by σ. Accordi whether the phase-spread is 1/Nth or 2/Nth of a pitch we have the narrow or wide phase-spread.

SYMBOLS USED.

C = total number of coils in a winding, or segments in commutator.
I = R.M.S. value of current.
N = number of phases.
Q = number of slot-pitches per pole-pitch (or slots per pole) $= S/2p$.
S = total number of slots in periphery.
S' = number of slots in a symmetrical polyphase system $= S/a$.
$\frac{C}{S} = \frac{u}{2}$ = segments per slot.

a = any integer, 1, 2, 3, etc.
= number of similar parts (or circuits) in a phase of a symmetrical winding.
e = instantaneous value of electromotive force.
$\bar{e}$ = maximum value of electromotive force.
m = number of coils in a group.
n = any integer.
p = total number of pole-pairs in a machine.
p' = number of pole-pairs in a symmetrical polyphase system $= p/a$.
q = number of slots per pole and phase $= Q/N$.
q_o = number of wound slots per pole and phase.
u = number of coil-sides per slot.
y_c = commutator pitch measured in commutator segments (or coils).
y_b and y_f = back and front winding pitches measured in coil-sides.
y_p = equipotential (or potential) pitch $= C/a$ segments (or coils).
y_{ph} = phase-pitch $= C/aN$ segments (or coils) $= S/aN$ slots.

β = angular phase-pitch in radians.
γ = angular slot-pitch in radians.
σ = angular phase-spread in radians.
ψ = angular phase displacement between the pressures induced in successive coils in the winding.

1. ARMATURE WINDINGS.

In a heteropolar machine, that is, a machine with alternate north and south poles, the periphery of p pole-pairs represents $2\pi p$ radians, in electrical measure. Denoting the total number of slots in the uniformly-slotted periphery by S, the angular slot-pitch in radians is then

$$\gamma = \frac{2\pi p}{S} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The phase of the pressure induced in a conductor depends chiefly on the position in the field of the slot in which the conductor lies, and only to a small extent on the position of the conductor in the slot. If no flux whatever passed through the slot, the phase of the pressure induced in each conductor in the slot would be the same. Consequently, in a slotted armature, the position of the slots in the field, or, in other words, the relation between the number of slots and the number of poles, is of fundamental importance. To examine this relation, then, we need only consider the slots filled with coils arranged to form a uniform winding over the periphery. For this purpose we can take an ordinary two-layer winding with two coil-sides per slot—one in the top and the other in the bottom layer. In this winding, the number of coils C is equal to the number of slots S. These coils can be joined up in many different ways, according to whether the constant phase displacement ψ between the pressures induced in successive coils is to be greater than, equal to, or less than the slot-pitch γ, as can be readily understood from the rules for lap and wave connections, which we shall consider presently.

Ignoring any harmonics that may be present in the pressure wave, that is, assuming a sinusoidal flux-distribution, the pressures induced in the successive coils a, b, c, etc., can be represented by vectors displaced from one another by the angle ψ, as shown in Fig. 1 (*a*), whilst the resultant pressure obtained by joining m coils in series is shown in Fig. 1 (*b*). (Small letters are used to denote instantaneous values, and a bar is added to denote maximum values.) If the m vectors in Fig. 1 (*b*) form a closed figure, as is the case whenever $m\psi = 2\pi$, 4π, . . ., or, in general, $2\pi a$, where $a = 1, 2, 3$, etc., then it is clear that $\sum_a^m e = 0$, and if the m coils represented by these vectors are joined in series to form a closed winding, no internal current will circulate.

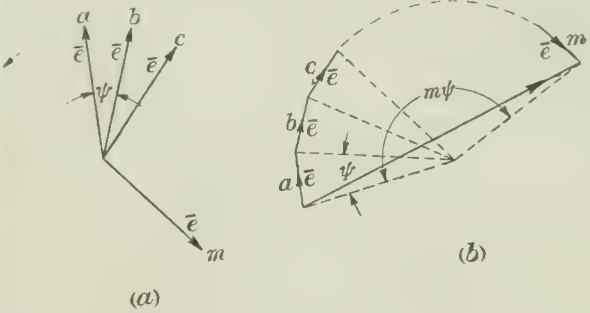

FIG. 1.—Pressures induced in successive coils of a winding.

(*a*) Vector diagram. (*b*) Resultant of vector diagram.

In the special case when $m\psi = 2\pi$, the m coils form, by definition, a symmetrical m-phase system. If a winding has a such systems all alike, that is, a similar sets of m coils each, it is said to be symmetrical. If like coils of the a similar parts of a symmetrical winding are joined in series or parallel, neither the phase nor the shape of the pressure wave will be affected in any way, nor can currents circulate between the several parts.

We shall now see how these conditions can be fulfilled in a winding.

(I) *Condition for obtaining a Closed Winding.*

A closed winding may be defined as a winding in which the sum of all pressures is zero at any instant, since no current of fundamental frequency can circulate in such a winding when all the coils are joined in series to form a closed winding.

In order that the sum of the pressures induced in the S coils in the winding may be zero, we must make the total phase displacement $S\psi = 2\pi a$, because only in this case do the S vectors form a closed figure.

We [illegible] then

$$S\psi = 2\pi a$$

and that the phase angle ψ must be (see Equation 1)

$$\psi = \frac{2\pi a}{S} = \frac{2\pi p}{S}\frac{a}{p} = \frac{a}{p}\gamma \quad . \quad . \quad . \quad (2)$$

Thus by making $\psi = a\gamma/p$, we obtain a winding in which $S\psi = 2\pi a$, and therefore $\sum^{S} e = 0$.

It will be seen presently that the rules for lap and wave connections are developed from the simple relation in Equation [illegible].

In the above argument, it is noticed that a is merely a number ; that is, $a = 1, 2, 3$, etc.

(II) *Condition for obtaining a Symmetrical Winding.*

If a winding in which $S\psi = 2\pi a$ has a similar parts, it can be called symmetrical, because the coils in each part then form a symmetrical polyphase system, in which the sum of the pressures is zero at any instant.

Let a be the highest common factor (H.C.F.) of the number of slots S and the number of pole-pairs p. Then $S/a = S'$ and $p/a = p'$ are both integers, and the above formulæ become

$$S'\psi = 2\pi \text{ and } S'\gamma = 2\pi p'.$$

Hence the phase angle ψ will now be

$$\psi = \frac{2\pi}{S'} = \frac{\gamma}{p'} \quad . \quad . \quad . \quad . \quad (3)$$

Thus by making $\psi = \gamma/p'$, we obtain a winding in which $S'\psi = 2\pi$, and therefore $\sum^{S'} e = 0$. Each set of S' vectors forms a closed polygon, and there are a such polygons exactly alike. Consequently such a winding has a similar parts, and each part forms a symmetrical S'-phase system, in which the sum of the S' pressures is zero at any instant.

In this case, then, a has a definite meaning—it is the H.C.F. of S and p, and denotes the number of similar parts in the winding, or the number of times the slot positions in the field recur.

Since from each of a similar systems a similar circuit can be taken, it follows that a represents the number of similar circuits possible in a symmetrical winding. These a similar circuits can be united to form one phase of a polyphase system—the series or parallel connection being used according to the pressure and current required. The several phases can then be interlinked in star or mesh, as desired, unless they are already joined in mesh to form a closed winding. When the circuits are connected in series, the same current flows through all ; when they are joined in parallel the current per circuit $I_c = I_p/a$, where I_p is the total current per phase.

In this paper the commonest symmetrical polyphase windings will be treated in subsection (IV). The chief of these are :—

Symmetrical 2-phase winding : 2 phases at 180° (continuous current).
Symmetrical 3-phase winding : 3 phases at 120°.
Symmetrical 4-phase winding : 4 phases at 90°.
Symmetrical 6-phase winding : 6 phases at 60°.

When the coils of a symmetrical winding are joined in series to form a closed winding, there will always be a coils at the same potential. These a equipotential coils are $S' = S/a$ coils apart, and must be connected to a common terminal by means of tappings or commutator brushes, in order to load the a similar parts of the closed winding uniformly. For this reason we call the distance between successive equipotential coils the equipotential (or, briefly, the potential) pitch, i.e. the potential pitch $y_p = S/a$ slots or C/a coils. Obviously, equipotential connectors (or equalizing rings) can be joined to any of the corresponding S′ phases in the a similar parts of the winding, when desired.

An interesting case of the mesh connection with the a systems in parallel is the continuous-current machine, where connection is made to a closed winding by means of commutator brushes. In this case a brush does not make connection with two similar circuits, but with the two phases at 180° of a symmetrical 2-phase system. The total current I_p in each phase is then equal to half the continuous current I_o, so that the current per circuit $I_c = I_p/a = I_o/2a$.

The above conditions can be summarized as follows :—

(I) When the total phase displacement of the S coils $S\psi = 2\pi a$, where $a = 1, 2, 3$, etc., then $\sum^{S} e = 0$, and the S coils can be joined in series to form a closed winding.

(II) When in addition to $S\psi = 2\pi a$, a is the H.C.F. of S and p, then $S'\psi = 2\pi$, and therefore $\sum^{S'} e = 0$, so that the S coils form a similar symmetrical S′-phase systems.

A winding which satisfies conditions (I) and (II) is called symmetrical, whilst a winding which satisfies condition (I) but not condition (II) is called unsymmetrical.

These conditions show clearly how the number of similar parts or circuits in a winding depends on the relation between the number of poles and the number of slots. When we come to deal with the actual windings themselves in the latter part of the paper, it will be found that a certain amount of confusion exists due to a slotting being used for a number of circuits different from the H.C.F. of S and p. In practice this often leads to undesirable results, as will be seen when we refer to two of the commonest examples. In an alternator it is quite common to use a slotting which gives the number of similar parts a equal to the number of pole-pairs p when only one circuit per phase is needed, with the result that tooth effects are repeated throughout the phase, whereas when $a \neq p$ (as for example $a = 1$) the tooth effects are suppressed by joining dissimilar pressures in series. On the other hand, in a commutator machine where the a parts are joined in parallel at the commutator or at the slip-rings it is very important to make the winding symmetrical, that is, the a paths exactly similar, to prevent sparking and the circulation of internal currents.

(III) *Examples of Symmetrical and Unsymmetrical Windings.*

To illustrate the foregoing, let us choose at random different numbers of slots S and of pole-pairs p, and show what windings with 2 conductors per slot are possible when we make $a = 1, 2, 3$, etc. The possible lap and wave windings are found from the closing rules derived from Equation (2), and given on page 29. Though single-layer windings might also be included in this table, nothing would be gained by their addition, for the symmetry or dissymmetry of a winding depends fundamentally on the relation between the number of poles and the number of slots, and not on the type of winding used.

Pole-pairs p	Total Slots S	H.C.F. of S and p	p'	S'	Assumed a	$\psi = \frac{a}{p}\gamma$	$S\psi = 2\pi a$	Conditions satisfied	Possible Windings
3	39	1	2	39	1	$\gamma/2$	2π	I and II	Symmetrical wave
,,	,,	,,	,,	,,	2	γ	4π	I	Unsymmetrical lap
,,	,,	,,	,,	,,	3	$3\gamma/2$	6π	I	Unsymmetrical wave
2	36	2	1	18	1	$\gamma/2$	—	—	Impossible *
,,	,,	,,	,,	,,	2	γ	4π	I and II	Symmetrical lap or wave
,,	,,	,,	,,	,,	3	$3\gamma/2$	—	—	Impossible
3	42	3	1	14	1	$\gamma/3$	—	—	Impossible
,,	,,	,,	,,	,,	2	$2\gamma/3$	—	-	,,
,,	,,	,,	,,	,,	3	γ	6π	I and II	Symmetrical lap or wave
3	41	1	3	41	1	$\gamma/3$	2π	I and II	Symmetrical wave
,,	,,	,,	,,	,,	2	$2\gamma/3$	4π	I	Unsymmetrical wave
,,	,,	,,	,,	,,	3	γ	6π	I	Unsymmetrical lap
3	40	1	3	40	1	$\gamma/3$	2π	I and II	Symmetrical wave
,,	,,	,,	,,	,,	2	$2\gamma/3$	4π	I	Unsymmetrical wave
,,	,,	,,	,,	,,	3	γ	6π	I	Unsymmetrical lap
4	48	4	1	12	1	$\gamma/4$	—	—	Impossible
,,	,,	,,	,,	,,	2	$\gamma/2$	—	—	,,
,,	,,	,,	,,	,,	3	$3\gamma/4$	—	—	,,
,,	,,	,,	,,	,,	4	γ	8π	I and II	Symmetrical lap or wave
4	47	1	4	47	1	$\gamma/4$	2π	I and II	Symmetrical wave
,,	,,	,,	,,	,,	2	$\gamma/2$	—	—	Impossible
,,	,,	,,	,,	,,	3	$3\gamma/4$	6π	I	Unsymmetrical wave
,,	,,	,,	,,	,,	4	γ	8π	I	Unsymmetrical lap
4	46	2	2	23	1	$\gamma/4$	—	—	Impossible
,,	,,	,,	,,	,,	2	$\gamma/2$	4π	I and II	Symmetrical wave
,,	,,	,,	,,	,,	3	$3\gamma/4$	—	—	Impossible
,,	,,	,,	,,	,,	4	γ	8π	I	Unsymmetrical lap
4	45	1	4	45	1	$\gamma/4$	2π	I and II	Symmetrical wave
,,	,,	,,	,,	,,	2	$\gamma/2$	—	—	Impossible
,,	,,	,,	,,	,,	3	$3\gamma/4$	6π	I	Unsymmetrical wave
,,	,,	,,	,,	,,	4	γ	8π	I	Unsymmetrical lap

* Cases are marked impossible when it is not possible to find windings, due to the impossibility of giving ψ the required values or to other reasons. For example, with 18 slots per pole-pair, it is clearly impossible to make ψ an odd multiple of $\gamma/2$.

Though windings are also possible when $a > p$, these have not been included in the above table, because, being unsymmetrical, they are not so important, and because the above table is merely intended to be illustrative, the complete tables being given later in the paper (see page 32).

(IV) *Conditions for obtaining a Symmetrical N-phase Winding.*

Though it is possible to have a similar S′-phase systems in a symmetrical winding, usually only a smaller number of phases N = 3, 4, or 6 is required. We must therefore see under what conditions the slotting for a symmetrical winding can be divided into N equal parts at an angle $\beta = 2\pi/N$ radians apart to form a symmetrical N-phase system. In other words, we must see when it is possible to derive a symmetrical N-phase system from S′ slots and p' pole-pairs.

First, with regard to the slots, let S′ be exactly divisible by N. We then get N equal phases displaced from one another by an angle $S'\psi/N = 2\pi/N = \beta$ (since $S'\psi = 2\pi$, in a symmetrical winding), which is what is needed. We can call the integer S′/N the phase-pitch measured in slots, and denote it by y_{ph}, that is, $y_{ph} = S'/N$.

Coming now to the poles, it is clear that $2\pi p'/N = p'\beta$ must give the correct phase displacement $2\pi/N = \beta$. This is the case when $p' = nN \pm 1$, where $n = 0, 1, 2, 3$, etc., for then $p'\beta = (nN \pm 1)2\pi/N = \pm 2\pi/N = \pm\beta$. That is to say, when $p' = nN \pm 1$ the same positions are obtainable for N phases in the field with p' pole-pairs as with one [illegible] than unity, and since S/N is to be an integer, it follows [illegible]

Since a symmetrical winding has *a* similar parts, it follows that each phase in the N-phase system will have *a* similar parts, and by connecting these *a* parts in parallel [illegible]

Thus to get a symmetrical N-phase winding, we must have a symmetrical winding (as defined in Equation 3) such that

$$[illegible] = \frac{S}{N} = \frac{S}{aN} = \text{integer} \quad (4)$$

and

$$[illegible]$$

where $a =$ H.C.F. of S and $p =$ number of similar parts (or circuits) per phase.

The numbers of slots that will satisfy Equation (4) for N = 3, 4, and 6, are determined in the following sections of the paper, and are tabulated for lap and wave windings on page 32, whilst the following table shows the relation between the number of phases N, the number of similar parts (or circuits, with parallel connection) per phase *a* and the number of pole-pairs *p* in the machine.

Table 1 shows that certain cases are not possible; for example, it is not possible to obtain a symmetrical 3-phase winding with only one or two similar parts per phase in a 6- or 12-pole machine, nor is it possible to obtain a symmetrical 4-phase pressure from an 8-pole machine unless we have four similar parts in each phase.

Unless a commutator is used, it is not necessary, and with some types of winding not possible, to wind all the slots in each of the N parts; but provided that all N phases are made equal and properly spaced, a symmetrical N-phase pressure is obtained.

An extension to the above rule for obtaining *a* similar circuits per phase enables us to get 2 *a* parallel circuits [illegible] 6-phase system is equivalent to two symmetrical 3-phase systems at 180°, so that by joining opposite phases I and IV, III and VI, and V and II in parallel, we get a symmetrical 3-phase system with the same number of circuits as the 6-phase system from which it is derived. It this way it is possible to get two circuits per phase in a 2-pole machine, [illegible] In a similar way it is possible to derive a hemisymmetrical [illegible] from a symmetrical 4-phase winding.

[illegible] can be halved by joining opposite phases [illegible]

[illegible] -le- and double-layer windings, occasion may be taken here to point out [illegible] The nature of the effects [illegible] When the pressures [illegible] field excitation, equality is established by reactive currents, which maintain the fluxes in the several machines at such a value that the sum of all the pressures round any circuit is zero at every instant. When there is a phase displacement between a machine pressure and a line pressure, a power component of current flows, and according to whether the phase of the machine pressure is ahead or behind that of the line pressure, the machine acts as a generator or motor. In the same way, when the pressures in the phases of a winding are unequal, reactive currents [illegible]

TABLE 1.

Possible Numbers of Similar Circuits per Phase in a Symmetrical N-phase Winding on a Machine with 2p Poles.

Number of Pole-pairs in Machine p	Number of Similar Circuits per Phase a	$c = \frac{p}{a}$	Possible Number of Phases N
1	1	1	3, 4, 6
2	1	2	3
	2	1	3, 4, 6
3	1	3	4
	3	1	3, 4, 6
4	1	4	3
	2	2	3
	4	1	3, 4, 6
5	1	5	3, 4, 6
	5	1	3, 4, 6
6	2	3	4
	3	2	3
	6	1	3, 4, 6
7	1	7	3, 4, 6
	7	1	3, 4, 6
8	1	8	3
	2	4	3
	4	2	3
	8	1	3, 4, 6
9	1	9	4
	3	3	4
	9	1	3, 4, 6
10	1	10	3
	2	5	3, 4, 6
	5	2	3
	10	1	3, 4, 6
11	1	11	3, 4, 6
	11	1	3, 4, 6
12	3	4	3
	4	3	4
	6	2	[illegible]
	12	1	3, 4, 6

Where continuous currents are concerned, experience has shown that sparking in rotary converters and flickering in the lights connected on each side of the middle wire of dynamos with static balancers have often been caused by unsymmetrical phases on the alternating-current side. Also, the trouble due to having the parallel circuits unlike one another in a commutator machine are well known. Of course, in some cases, like the rotor of a small induction motor, a certain amount of dissymetry may be harmless.

(V) *Phase-spread and Coil-span.*

In each pole-pitch the coil-sides of each phase are spread over a definite arc—this arc we shall call the phase-spread, and denote by σ (angular measure). According to the way the winding is arranged, the phase-spread can be made equal to 1/Nth or 2/Nths of the pole-pitch, or $\sigma = \pi/\mathrm{N}$ or $2\pi/\mathrm{N}$ radians. With a narrow phase-spread, $\sigma \leqq \pi/\mathrm{N}$, and with a wide phase-spread $\sigma \leqq 2\pi/\mathrm{N}$ radians.

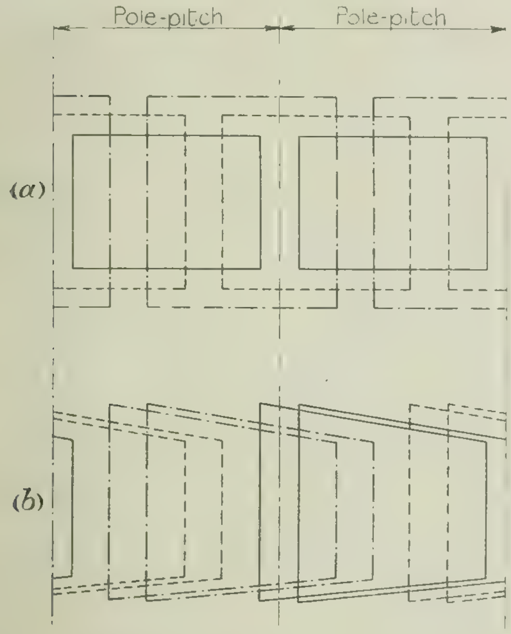

FIG. 2.—Equivalent constant-span coils in single-layer winding.

(*a*) Actual coils (variable span). (*b*) Equivalent coils (constant span).

In a double-layer winding the coil-span is usually constant and approximately equal to a pole-pitch, the coils being arranged in two layers and distributed uniformly over the armature periphery (see Fig. 8). In a single-layer winding, the coils can have a constant span, as in the mush winding; but winding the coils one inside the other forms a better arrangement for high-tension work and is preferred by some makers for all voltages. The variable coil-span, however, is due merely to the arrangement of the overhang, and by changing this we can obtain constant-span coils without affecting the position of the coil-sides in the slots in any way (see Fig. 2).

Both the phase-spread and the coil-span have a direct bearing on the output of the winding. To obtain the largest output from a given number of phases, the mean coil-span should equal the pole-pitch to make the coil-span factor unity, and the narrow phase-spread should be used to obtain a high distribution factor.[*] The influence of the phase-spread also explains why a larger output is obtained from an increased number of phases when the mean span of the coils in each phase is kept equal to the pole-pitch.

2. SINGLE-LAYER WINDINGS.

(I) *Arrangement of Single-layer Windings.*

The peculiarity of the single-layer winding is the use of one coil-side per slot, so that every coil fills two slots. Consequently if the coils of a phase are to lie in adjacent slots, as is usual in single-layer windings, each pole-pair must be divided into 2 N equal parts, two of which are monopolized by each phase. The phase-spread in a single-layer winding is then $\sigma = 2\pi/2\mathrm{N} = \pi/\mathrm{N}$ radians. It is also possible to obtain a phase-spread of $2\pi/\mathrm{N}$ radians in a single-layer winding by spreading the coil-sides of a phase over the wider arc and filling the empty slots by the coil-sides of another phase; but owing to the reduced output obtainable with the wide phase-spread, this arrangement is only resorted to in special cases, as, for example, in a 3-phase winding when it is desired to suppress the third harmonic in the phase pressure.

In single-layer windings, then, it is standard practice to use the narrow phase-spread, and a number of such polyphase windings are represented diagrammatically in Fig. 3, where a circle denotes a pole-pair of 2π radians. The circle is divided into 2 N parts, and single- and double-dashed numerals are used to denote the two sets of coil-sides in each phase. The phases can be interlinked as desired—thus diagrams *a–e* represent hemisymmetrical windings having 1, 2, 3, 4, and 6 phases respectively; whilst *f*, *g*, *h*, and *k* represent symmetrical 2, 3, 4, and 6-phase windings.

It is seen in Fig. 3 that different conditions arise according to whether the number of phases N is even or odd. Diagrams *a–e* and *g* show that with the mean coil-span equal to a pole-pitch, it is possible to obtain any hemisymmetrical N-phase winding, but only a symmetrical N-phase winding when N is odd. When N is even, a symmetrical N-phase winding is obtainable by making the mean coil-span equal to $(\mathrm{N}-1)/\mathrm{N}$ times the pole-pitch, as shown in diagrams *f*, *h*, and *k*. The relative outputs given on the diagrams are calculated for uniformly distributed windings, that is, for a phase-spread $= \pi/\mathrm{N}$.

The diagrams in Fig. 3 clearly show how two phases in which the pressures are equal and opposite can be joined in parallel or series to form a single phase. For example, in the symmetrical 6-phase winding in diagram *k*, the pressures in phases I and IV are equal and opposite, and by combining each such pair we get the hemisymmetrical 3-phase winding in diagram *c*, or the symmetrical 3-phase winding in diagram *g*. In diagram *k*, where $\mathrm{N}=6$ is even, the mean coil span is equal to $(\mathrm{N}-1)/\mathrm{N} = 5/6$ths of the pole-pitch; whilst in diagram *g*, where $\mathrm{N}=3$ is odd, the mean span equals the pole-pitch. Similarly the hemisymmetrical 2-phase winding with the mean span equal to the full-pitch in diagram *b* can be obtained from the symmetrical 4-phase winding with the mean coil-span equal to three-quarters of the pole-pitch in diagram *h* by combining phases I and III to form phase I and phases II and IV to form phase II. Or, again, the 1-phase winding in diagram *a* can be derived from the 2-phase winding in diagram *f*, by joining phases I and II in series or parallel.

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[*] S. P. SMITH and R. S. H. BOULDING: "The Shape of the Pressure Wave in Electrical Machinery." *Journal I.E.E.*, 1915, vol. 53, p. 205.

The advantage of obtaining an N-phase winding with full-pitch coils from a 2 N-phase winding with short-pitch

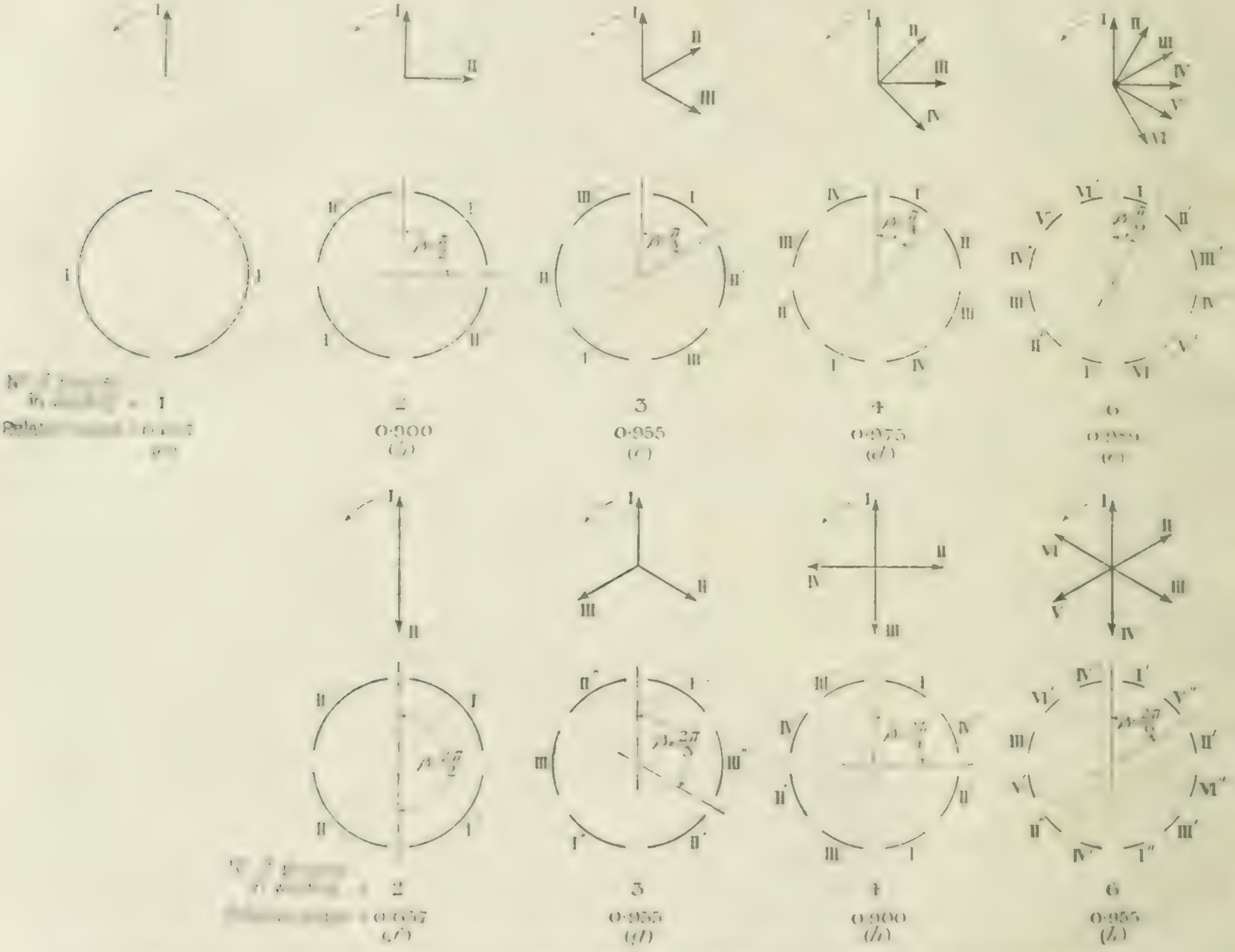


Fig. 3.—Diagrammatic arrangements of single-layer windings to obtain N phases with narrow phase-spread (σ = π ÷ N).

[illegible]

coils is threefold. First, the two parts can be joined in parallel, thereby doubling the number of circuits in a [illegible], thereby reducing the copper and heating in this part of the winding. [illegible] number of phases. Of course, when the series connection [illegible] than the other. This is equivalent to [illegible]

(II) *Number of Armature Slots.*

In single-layer windings it is common practice for a phase to have the same number of coils in each pole-pair. Let q_0 denote the number of coils per phase in each pole-pair. These q_0 coils require $2 q_0$ slots, so that for the N phases there must be $2 q_0 N$ slots per pole-pair, or in p' pole-pairs there must be $2 q_0 N p'$ slots. The total number of slots S′ in the p' pole-pairs can be written

$$S' = 2 q_0 N p' + x$$

where x denotes the number of slots in the p' pole-pairs not needed by the q_0 coils per group, and will be left empty when all groups are alike—see sub-section (*a*) below. If the x slots are wound, some groups will have more coils than others—see sub-section (*b*) below.

In order to obtain a symmetrical N-phase winding, the number of slots S′ must satisfy Equation (4), that is, the phase-pitch must be

$$y_{ph} = \frac{S}{aN} = \frac{S'}{N} = 2\,q_0\,p' + \frac{x}{N} \text{ slots} \quad . \quad . \quad . \quad (5)$$

where $p' = nN \pm 1 = p/a$.

Since y_{ph} must be a whole number and $2\,q_0\,p'$ is integral, it follows that the number of extra slots x in the p' pole-pairs must be divisible by the number of phases N, and each phase-pitch contain x/N extra slots.

The total number of slots S in the machine is then

$$S = S'a = 2\,q_0\,N\,p + x\,a \quad . \quad . \quad . \quad (5a)$$

In the common 3-phase single-layer winding, this becomes

$$S = 6\,q_0\,p + x\,a \quad . \quad . \quad . \quad . \quad . \quad . \quad (5b)$$

where $x = 0$, 3, 6, etc., and $a = p/p' = p/(3\,n \pm 1)$ is an integer $\gtreqless p$.

As these expressions are so simple, there is no need to tabulate the slottings for single-layer windings, and we shall therefore only consider the general cases.

(*a*) *Whole number of slots per pole.*—In most single-layer windings, the number of slots per pole Q is an integer. In this case every pole-pair is alike and forms a complete N-phase system. Thus $S' = 2\,q_0\,N + x$ and $Q = q_0\,N + x/2$ where x can be zero or any multiple of N. The total number of slots $S = S'p$, since $a = p$ when $p' = 1$.

An interesting relation holds when N is even and the polyphase winding is symmetrical, as pointed out in connection with Fig. 3. In this case the mean coil-span equals $(N - 1)/N$ times the pole-pitch, but by halving the number of phases we double the number of circuits and make the mean span equal to the pole-pitch. The important case in practice is when a 3-phase winding has a whole number of slots per pole. In this case the slotting is always that of a symmetrical 6-phase winding. Thus when $N = 6$, $Q = 6\,q_0 + \frac{1}{2}x$. If now $x = 0$, then Q is a multiple of 6, that is an even multiple of 3, so that the 6-phase winding consists of two 3-phase windings, which can be joined in series or parallel. If $x = 6$, $Q = 6\,q_0 + 3$; that is, Q is an odd multiple of 3, so that we have a symmetrical 6-phase winding with 3 empty slots per pole, or a symmetrical 3-phase winding with $Q/3 = 2\,q_0 + 1$ slots per phase and pole. In the latter case there are not two equal circuits per phase per pole-pair when all slots are wound, but this is immaterial when only the series connection is required. It is thus seen that with a whole number of slots per pole, the slotting for a symmetrical 3-phase winding is the same as that for a symmetrical 6-phase winding, and it is due to this fact that it is possible to obtain a 3-phase single-layer winding with one circuit per pole and phase.

When the number of slots per pole is integral, the same slot positions recur under every pole, and the coil-sides of the whole winding can only occupy Q positions in the field. Consequently, any effect due to the spacing of the slots or the swinging of the flux is repeated under every pole and appears undiminished in the phase pressure in the form of a spacing ripple or a tooth ripple. Thus for obtaining a smooth wave for the phase pressure we have the worst possible conditions with a whole number of slots per pole. There are several ways of suppressing the effects of the slots and teeth, most of which make the winding equivalent to a uniformly distributed winding. Thus by skewing the slots or the pole-shoes by an amount equal to the slot-pitch this result is obtained. An equally effective method, and one that is often simpler and cheaper than the foregoing from the works' point of view, is to make the number of slots per pole fractional by adding extra slots.

(*b*) *Fractional number of slots per pole.*—When Q is a fraction, the coil-sides do not occupy the same position in the field under the different poles, consequently the effect of the teeth is not reproduced throughout the phase. Expressed mathematically, we can say that $2\,Q + x$ and $2\,Q - x$, where $x = 1$, 3, 5, etc., no longer represent harmonics when Q is a fraction, whereas they do so when Q is an integer, and have a high winding factor f_x, when x is small (see footnote on page 23).

We shall only consider the practical case of the symmetrical 3-phase winding. Inserting $N = 3$ in Equation (4), we have $y_{ph} = S/3a = S'/3$.

The coils will occupy the greatest number of positions in the field when $a = 1$ and $p' = p$, that is, when there can be only one circuit per phase. We can always make $a = 1$ unless p is a multiple of 3. If p is a multiple of 3, we must make a a multiple of 3 so that $p' = p/a = 3\,n \pm 1$, is not a multiple of 3, and so obtain a similar parts per phase—see Table 1. For example, when $p = 3$ we must take $a = 3$, so that $p' = 1$; with $p = 6$ we can take $a = 3$ to make $p' = 2$, or $a = 6$ to make $p' = 1$. With $a = 3$, the slot positions in the field repeat themselves 3 times; with $a = 6$, 6 times.

(1) *Use of empty slots.*—The simplest way to make Q fractional is to have a number of extra slots not needed by the winding. From Equation (5) we get, for $N = 3$, the phase-pitch $y_{ph} = 2\,q_0\,p' + x/3$. Thus x must be a multiple of 3.

Taking $x = 3$ as the smallest number of empty slots that can be added, we have, when $p' = 3\,n \pm 1 = p$, $S' = 3\,y_{ph} = 6\,q_0\,p' + 3 = S$. This gives the largest number of positions possible in p pole-pairs with a symmetrical 3-phase winding, for in this case the slot positions in the field never recur and there can only be one circuit per phase. Thus with $x = 3$ empty slots and $p = 3\,n \pm 1$, we have:

Total slots, $S = 6\,q_0\,p + 3$,
Slots per pole, $Q = S/(2\,p) = 3\,q_0 + 3/(2\,p)$,
Slots per phase and pole, $q = Q/3 = q_0 + 1/(2\,p)$,
Phase-pitch in slots, $y_{ph} = 2\,q_0\,p + 1$.

When $p' = 1$, or in a 2-pole machine, with three extra slots we get $S' = 6\,q_0 + 3 = 2\,Q$, so that Q = an integer + ½. This also has the effect of suppressing the tooth or spacing ripples owing to the action of the coil-span (see footnote on page 23).

In some cases it is found desirable to make $x = 6$, that is, to use 6 empty slots, but it must be remembered that with an even number of pole-pairs this makes two a common factor of S and p, or $p' = p/2$ and $a = 2$, thus giving two similar parts and only half the maximum number of possible positions in the field for each phase.

(ii) *Use of unequal coil groups.*—It is clear that when the number of extra slots in the machine is an even multiple of 3, i.e. when $x = 6\,n$, these slots can be wound and an equal number of extra coils allotted to each phase. In this way the coil groups in the several pole-pairs are made unequal.

Taking the case of 6 extra slots in p' pole-pairs, we get one extra coil per phase in each circuit. Thus in a 4-pole [illegible] group there will be q coils and in the other $q_0 + 1$, thus [illegible]

Generally speaking, unequal coil groups are not desirable in practice, owing to the varying magnetomotive force from pole to pole and the constructional complications.

Example.—As an example of the use of extra slots, we can consider an 8-pole, 3-phase machine with a normal slotting for 2 slots per pole and phase, i.e. $q_0 = 2$. The total number of slots is then 48, and according to whether we make the mean coil-span equal to the pole-pitch or to 5/6ths of the pole-pitch, we get a 3- or 6-phase winding, so that a 3-phase [illegible]

When extra slots are used, we get the following alterna[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	51	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	54	[illegible]
4	[illegible]	[illegible]	15	[illegible]	[illegible]

[illegible] —two usual and three unusual. All the latter are effective in suppressing tooth effects—the suppression in the case of S = 15 slots per pole-pair being due to the fact that the coil-span differs from the pole-pitch by an odd number of half slot-pitches (see footnote on page 23).

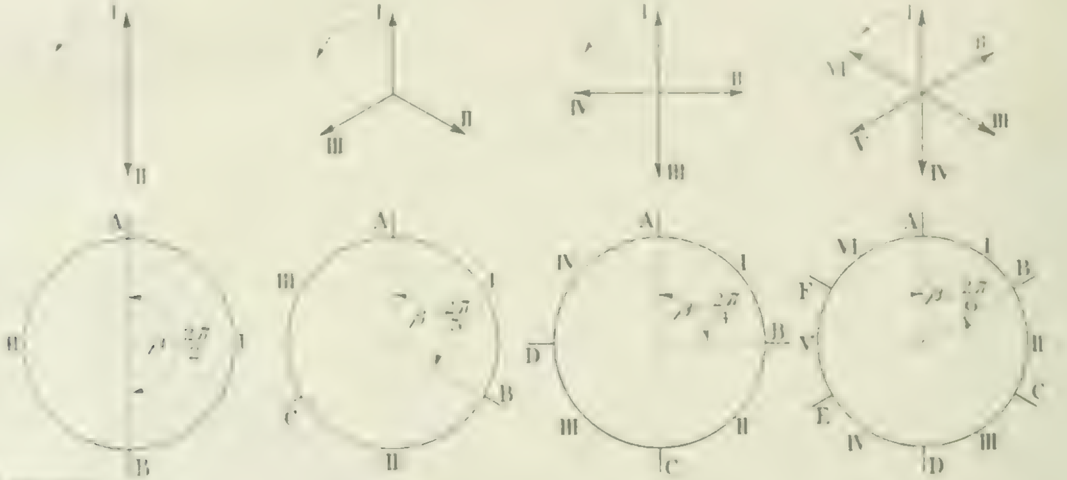
3. [illegible] Windings.

(1) [illegible]

When the sides of the coils are in two layers in the slots, one side of a coil lies in the top layer in one slot and in the bottom layer in some other slot, usually about a pole-pitch away. Generally all the coils are identical and arranged so that they can be joined in mesh, by means of lap or wave connections, to form a closed winding (see Fig. 8).

The smallest number of coil-sides per slot is 2, but any even number can be used, the commonest numbers being 4, 6, 8, and 10 coil-sides per slot. Since only one side of a coil has a place in either layer, the 2π radians need only be divided into N equal parts—one part being allotted to each phase. In this case the phase-spread $\sigma = 2\pi/N$ radians. When, however, a commutator is not used, it is usual and better to divide the 2π radians into $2N$ parts and so reduce [illegible] layer winding, in order to obtain the larger output.

[illegible] the phase angles between the pressures is 2π radians and the resultant pressure is zero. Consequently the coils can be joined in mesh to form a closed winding, and according to the relation between the number of coils and the pitch between successive coils, the a systems can be made inde[illegible] of the successive coil until the winding closes.)



[illegible] = 2	3	4	6
0·707	0·827	0·900	0·955

[illegible]

Permanent connections to a closed winding take the form of tappings—the corresponding equipotential points in each of the a systems being connected together to place the latter in parallel. Each point where a closed winding is tapped makes connection with the start of one phase and the finish of another.

In what follows, only one of the a similar polyphase systems need be considered, and again a circle will be used to represent the commutator bars or joints between the coils forming the field displacement of 2π radians. This circle has then to be split up to form the N phases. Pressures can be tapped off a closed winding in two ways: (i) polygon tappings; (ii) diametral tappings.

(i) *Polygon tappings.*—For an N-phase system, the circle is simply divided into N equal parts by means of N equidistant tappings, and the loads are placed across adjacent tappings. Tappings taken off a closed winding in this way can be conveniently called "polygon" tappings. The angular phase-pitch β is then equal to the angular phase-spread σ, that is, $\beta = \sigma = 2\pi/N$.

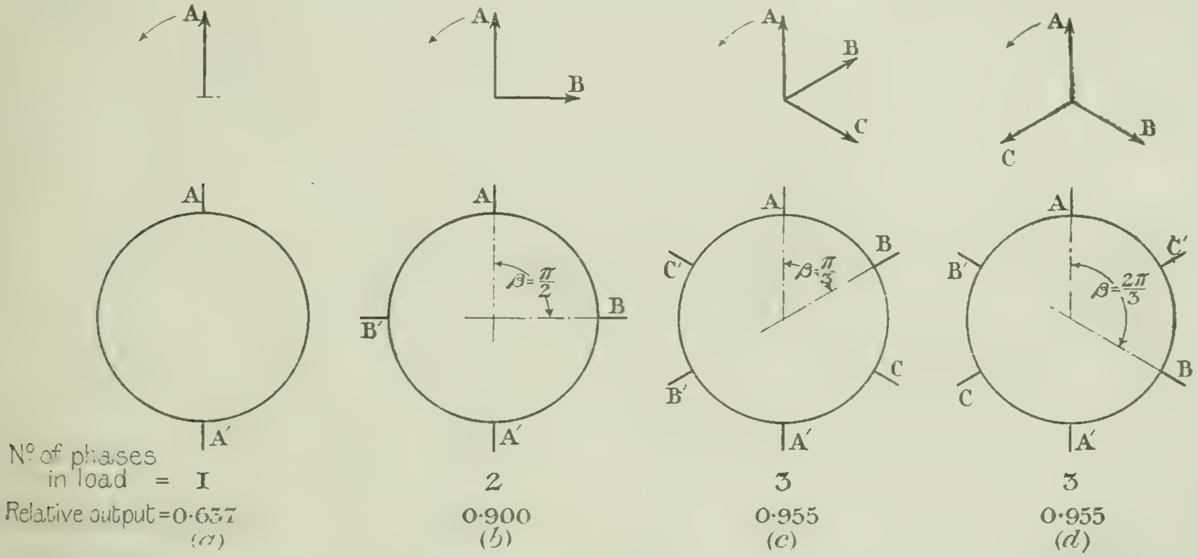


FIG. 5.—Diagrammatic arrangement of closed double-layer windings with full-pitch coils to obtain N phases with phase-spread $\sigma = \pi$, by means of diametral tappings.

(a) to (c)—Hemisymmetrical systems ($\beta = \pi/N$). (d)—Symmetrical system ($\beta = 2\pi/N$).

In this way it is possible to obtain any symmetrical N-phase system of pressures, as shown in Fig. 4. The pressures and currents in such a system are thus those in a mesh-connected system.

(ii) *Diametral tappings.*—Here the winding is tapped at twice as many points as the number of phases required, and each load phase is formed by placing two opposite winding phases in parallel by means of diametral tappings. Thus for an N-phase load, we have 2 N tappings—two exclusively for each phase.

The angle between successive load phases is then $2\pi/(2N) = \pi/N$ radians, so that the hemisymmetrical systems in Fig. 5 (*a–c*) are obtained. When N is odd, however, the system can be loaded symmetrically by connecting the phases as shown in Fig. 5 (*d*)—thus diagram *d* is the common way of loading a rotary converter with 6 slip-rings.

It is easily shown that the method of diametral loading of a closed winding yields the same output as is obtained from an open winding with a phase-spread of π/N.

(*b*) *Open double-layer windings.*—If a commutator is not used, the windings in Fig. 4 can be opened at the points tapped, as shown in Fig. 6, where the top coil-sides are indicated by full and the bottom by dotted lines. Each phase has now its own start and finish and can be loaded independently, or the phases can be interlinked in star (the original closed winding with polygon tappings is the mesh connection in Fig. 4); but the phase-spread and phase-pitch remain unaltered, that is, $\sigma = \beta = 2\pi/N$.

When full-pitch coils are used, it is seen from Fig. 6 that phases r and $r + \frac{1}{2}N$ overlap completely when N is even, whilst two phases half overlap whenever N is odd. It is much better, however, to halve the phase-spread in order to obtain a larger output with the same number of phases in the load. To do this, the 2π radians are divided into 2 N parts, thereby making the phase-spread $\sigma = 2\pi/(2N) = \pi/N$, and the two parts which completely overlap are joined in parallel or series, as desired, to form a single phase. This is always possible, since 2 N is always even. To join the two equal and opposite parts in series, either both finishes or both starts must be joined together; whilst to join them in parallel, the start of one must be connected to the finish of the other, and conversely. The windings thus obtained are represented diagrammatically in Fig. 7, and it is seen that with full-pitch coils any hemisymmetrical system whatever can be obtained in this way, but a symmetrical system is only obtainable when N is odd. Thus, by opening a double-layer winding at 2 N equi-

[illegible] N [illegible] is obtained with a [illegible] N [illegible]

[illegible]

Whereas single-layer windings are solely used for obtaining [illegible] N [illegible] the double-layer

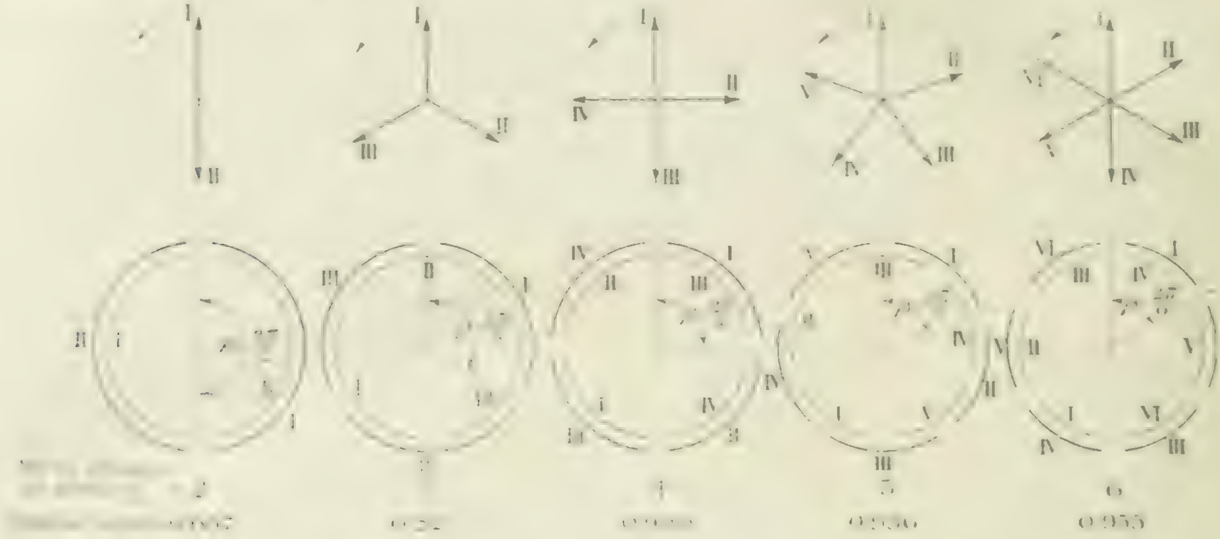
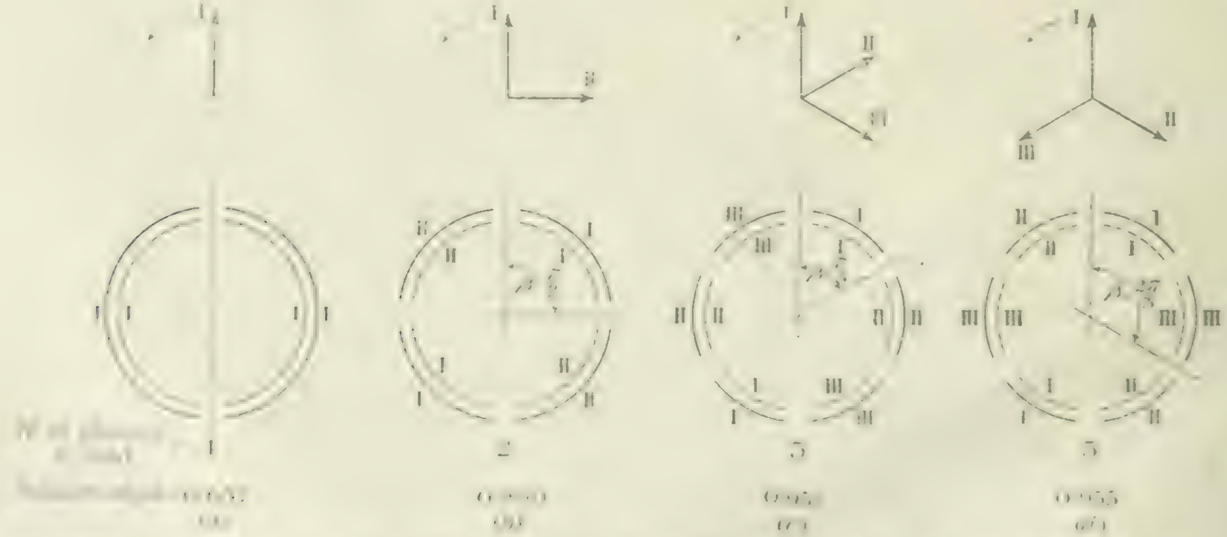


FIG. 6.—Diagrammatic arrangement of open double-layer windings with full-pitch coils to obtain N symmetrical phases [illegible]



[illegible]

[illegible] [illegible]

When no commutator is needed, an open winding with [illegible] it is customary [illegible] winding [illegible]

There are two common modes of connecting up the coils [illegible] used when successive coils *a* and *b* lie under the same pole-pair, and the wave when they lie under adjacent pole-pairs

[illegible] radians (see Equation 2). In cases where the number of coil-sides per slot *u* is greater than 2, for the purpose of connecting up the coils we can imagine there are as many slots as there are coils or commutator segments, i.e. we make $S = C$. Equation (2) then becomes

$$\left.\begin{aligned} C\,\psi &= 2\,\pi\,a \\ \text{and}\qquad \frac{\psi}{\gamma} &= \frac{a}{p} \end{aligned}\right\}\quad . \; . \; . \; . \; . \; . \; . \; . \quad (6)$$

where ψ is now the phase displacement between successive coils when $u = 2$, and γ the angular pitch of the commutator segments (or joints) or of the slots when $u = 2$.

The number of joints or segments between successive coils in the winding is called the commutator pitch, and will be denoted by y_c; thus y_c must contain an exact number of commutator-bar pitches γ.

Though this formula enables us to deduce the rules for closed lap and wave windings, i.e. windings in which $\Sigma\, e = 0$, so that no circulating currents of fundamental frequency can flow, it does not follow that such windings will have similar parts. When we apply the conditions for obtaining a similar circuits per phase with the actual number of slots $S = 2\,C/u$—for either a continuous or alternating pressure—we shall find that the number of symmetrical windings obtainable is much smaller than the number of closed windings.

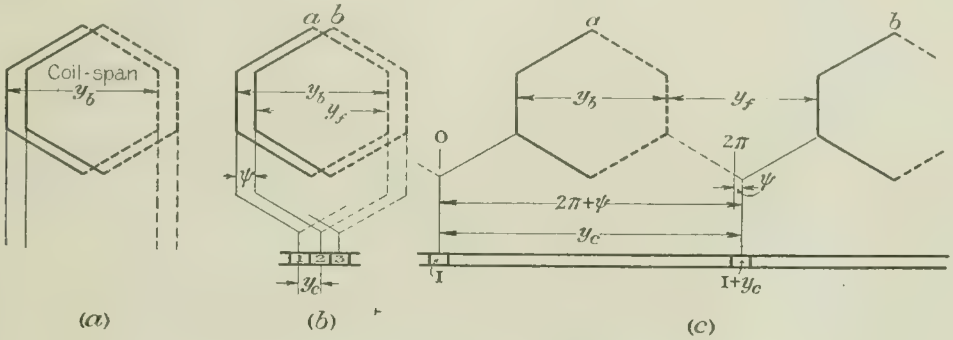


FIG. 8.—Double-layer windings.

(a) Coils of double-layer windings. (b) Lap connection. (c) Wave connection.

(a) *Closing rule for lap windings.*—With the lap connection, the finish of one coil is joined to the start of another under the same pole-pair, so that the angle $y_c\,\gamma$ between successive coils on the armature is equal to the phase displacement ψ between them. Applying $y_c\,\gamma = \psi$ to Equation (6), we get

$$\left.\begin{aligned} y_c &= \frac{\psi}{\gamma} = \frac{a}{p} \\ \text{or}\qquad a &= y_c\,p = p,\ 2\,p,\ 3\,p,\ \text{etc.} \end{aligned}\right\}\quad . \; . \; . \quad (7)$$

Thus a closed lap winding can be obtained by making a a multiple of the number of pole-pairs p.

(b) *Closing rule for wave windings.*—With the wave connection, the finish of one coil is joined to the start of another under the next pole-pair, so that the angle $y_c\,\gamma$ between successive coils on the armature is equal to $2\,\pi \pm \psi$. Applying $y_c\,\gamma = 2\,\pi \pm \psi$ to Equation (6), we get

$$\left.\begin{aligned} y_c &= \frac{2\,\pi \pm \psi}{\gamma} = \frac{2\,\pi}{\gamma} \pm \frac{\psi}{\gamma} \\ &= \frac{C}{p} \pm \frac{a}{p} = \frac{C \pm a}{p} \end{aligned}\right\}\quad . \; . \; . \; . \quad (8)$$

where $C\,\gamma = 2\,\pi\,p$, when we make $S = C$.

Hence in a closed wave winding, $a = p\,y_c - C$, so that a can be greater than, equal to, or less than p.

It is easy to see that the H.C.F. of C and y_c determines the number of independent windings on the armature with either lap or wave connections.

(III) *Conditions for obtaining Symmetrical Lap and Wave Windings.*

The conditions for obtaining closed lap and wave windings are set forth in Equations (7) and (8), whilst the conditions for obtaining a similar circuits are given in Equation (3). We must now combine these to find the conditions for obtaining symmetrical lap and wave windings. To get a closed winding, the resultant of the vector diagram is merely a closed figure subtending $2\,\pi\,a$ radians at the centre, whereas in a symmetrical winding there are a similar polygons in the resultant diagram, each subtending an angle of $2\,\pi$ radians at the centre. It is only when the winding is symmetrical that there are a coils which are always at the same potential, and which therefore can be properly joined together by means of an equalizing or slip-ring or by a commutator brush.

(a) *Symmetrical lap windings.*—In Equation (7) it is seen that a can be any multiple of p in a closed lap winding, whilst in Equation (3) it is seen that p/a must be integral in order to get a like parts. The only value of a which satisfies both these equations is obviously $a = p$. Further, since the number of slots in each of the a parts must also be integral, we must have $S/a = S/p$ a whole number, i.e. there must be a whole number of slots per pole-pair.

Hence it is only possible to obtain a symmetrical lap winding with as many similar parts (or circuits) as there are pole-pairs and with a whole number of slots per pole-pair, or

$$\left.\begin{aligned} a = p, &\quad \text{or}\quad p' = 1 \\ \text{and}\qquad S' = \frac{S}{p} &\quad \text{or}\quad S = p\,n \end{aligned}\right\}\quad . \; . \; . \; . \; . \quad (9)$$

where $n = S' =$ any integer.

The number of coil-sides per slot in a symmetrical lap winding is not restricted in any way, provided that we make $C = \frac{1}{2}\,u\,S$, i.e. avoid idle coils.

The $a = p$ equipotential joints or segments to be connected together at an equalizing or slip-ring are equi-

[illegible]

The above [illegible] are summarised in Table I, whilst illustrative examples are given in sub-section (V).

The condition that $x = [illegible]$ and C/S must have no common factor greater than unity at once restricts the number of segments per slot C/S that can be used with given numbers of poles as shown below.

Segments per Slot in Symmetrical Wave Windings.

Pole-pairs p'	1	2	3	4	5	6	7	8	9	10	11	12
Segments per slot C/S	any	1, 3, 5, 7	1, 2, 4, 5, 7, 8	1, 3, 5, 7	1, 2, 3, 4, 6, 7, 8	1, 5, 7	1 to 6, 8	1, 3, 5, 7	1, 2, 4, 5, 7, 8	1, 3, 7	any	1, 5, 7

[illegible] *al wave windings.*—In Equation (8), the [illegible] $C = p y \pm a$. Since there are to be no idle coils, i.e. the segments per slot $C/S = u/2$, we can write for the number of slots in a closed wave winding

$$S = \frac{C}{u/2} = \frac{C}{C/S} = \frac{p y}{C/S} \pm \frac{a}{C/S}$$

[illegible] by a we get

$$\frac{S}{a} = \frac{p}{a} \cdot \frac{y_a}{C/S} \pm \frac{1}{C/S}$$

[illegible] Equation (3) to obtain a identical S'-phase systems, we must have $S' = S/a$ and $p' = p/a$, that is, S/a and p/a must both be integers, or

$$S' = p' \frac{y_a}{C/S} \pm \frac{1}{C/S}$$

Now by the ordinary rules of division we can write

$$\frac{y_a}{C/S} = n + \frac{x}{C/S} \text{ or } y_a = n\,C/S + x$$

where n is any integer and x is an integer less than C/S.

Substituting for y_a we then get

$$S' = \frac{p'}{C/S}\left(n\,\frac{C}{S} + x\right) \pm \frac{1}{C/S}$$

$$= p' n + p' \frac{x}{C/S} \pm \frac{1}{C/S}$$

$$= p' n + \frac{1}{C/S}(p' x \pm 1) \qquad (10)$$

[illegible] must be a whole number. Now clearly $p' n$ [illegible] by C/S. This will be obviously impossible [illegible]

The above table, then, shows the number of coil-sides per slot, $u = 2\,C/S$, up to 16, possible with any number of poles up to 24 in a symmetrical wave winding.

To examine the restriction that x and C/S must have no common factor > 1, let us write

$$\frac{1}{C/S}(p' x_1 + 1) = A \text{ and } \frac{1}{C/S}(p' x_2 - 1) = B$$

where x_1 and x_2 must be values of x which have no common factor with C/S greater than unity, and which make A and B whole numbers. We can now determine A and B and x_1 and x_2 as follows:—

Since A and B are integers, $A + B = \frac{p'}{C/S}(x_1 + x_2)$ must be integral. Now p' and C/S have no common factor > 1, therefore $x_1 + x_2$ must be divisible by C/S. But, by assumption, x_1 and x_2 are each less than C/S, so that their sum must be less than $2\,C/S$; hence it is only possible to have $x_1 + x_2 = C/S$. Substituting for $x_1 + x_2$ we get $A + B = p'$.

Inserting A and B in Equation (10), and disregarding any difference between n and $n + 1$ (since n can be any integer),

$$S' = p' n + A \text{ or } p' n + B$$
$$= p' n + A, \text{ or } p'(n + 1) - A$$
$$= p' n - A$$
$$= p' n + B$$

Since $p' n + A$ gives the same series of numbers as $p' n - B$, and $p' n - A$ the same series as $p' n + B$, we can write for the number of slots in a symmetrical wave winding

$$S' = p' n \pm K \qquad (11)$$

where $K = A$ or B, according to which value we choose to give it. In what follows, for the sake of simplicity we shall always make K equal to the smaller of these two integers.

We now draw up the following table for x_1 and x_2 for given values of C/S.

[illegible] *Unity.*

C/S	1	2	3	4	5	6	7	8
x_1 and x_2	0 and 1	1 and 1	1 and 2	1 and 3	1 and 4 2 and 3	1 and 5	1 and 6 2 and 5 3 and 4	1 and 7 3 and 5

This enables us to evaluate K for given values of p' and C/S, for we have only to work out A and B and tabulate the lower value. The spaces denoted by a dash are the impossible cases of C/S with particular values of p', as given by Equation (10) and already determined.

Value of K in Equation (11).

Values of C/S.	Values of $p' = p/a$: 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	–	1	–	2	–	3	–	4	–	5	–
3	1	1	–	1	2	–	2	3	–	3	4	–
4	1	–	1	–	1	–	2	–	2	–	3	–
5	1	1	1	1	–	1	3	3	2	–	2	5
6	1	–	–	–	1	–	1	–	–	–	2	–
7	1	1	1	1	2	1	–	1	4	3	3	5
8	1	–	1	–	2	–	1	–	1	–	4	–

Having found S′ in this way, $S = S' a$ for any value of a.

Table 3, showing the number of slots and coil-sides per slot in symmetrical wave windings can now be drawn up and, wherever possible, the designer should adhere strictly to these conditions.

The following example will illustrate how K is determined. Let $p' = 4$ and $C/S = 3$. Then $A + B = p' = 4$, and $x_1 + x_2 = C/S = 3$. The possible values of x_1 and x_2 are 1 and 2. Taking $x_1 = 2$, then $A = \frac{1}{3}(4 \times 2 + 1) = 3$; and taking $x_2 = 1$, $B = \frac{1}{3}(4 \times 1 - 1) = 1$. We thus take $K = B = 1$, and get for the possible numbers of slots $S' = p' n \pm K = 4n \pm 1$, as shown in Table 3.

If $a = 1$, as in the common wave winding, then $p' = p = 4$, and $S' = S$. Thus the total number of slots in an 8-pole machine with a symmetrical wave winding and 6 coil-sides per slot is $S = 4n \pm 1$.

Similarly, if $a = 2$, then $p = p' a = 4 \times 2 = 8$; and $S = a S' = 2 S' = 2(4n \pm 1) = 8n \pm 2$. In this way, Table 3 has been drawn up for machines with any number of poles up to 24 and any number of coil-sides per slot up to 16.

The potential pitch, $y_p = C/a$. Each tapping forms the start of one phase and the finish of another. With diametral tappings, these two phases are equal and opposite, so that the current divides equally between them. In this way each tapping represents two parallel circuits, so that tapping a points by means of a commutator brush or a slip-ring makes connection with $2a$ circuits. This only holds, however, for the case when the phases are taken over 180°, as with diametral tappings or in a continuous-current machine, and corresponds with the case of a single-layer winding, where a 3-phase winding with $2a$ circuits per phase is obtained by joining in parallel the equal and opposite phases of a 6-phase winding.

(IV) *Conditions for obtaining Symmetrical N-phase Lap and Wave Windings.*

The conditions for obtaining a symmetrical N-phase system of pressures given in Equation (4) show that we must have a symmetrical winding where S′ is exactly divisible by N and $p' = nN \pm 1$.

(*a*) *Symmetrical N-phase lap windings.*—In a symmetrical lap winding, $p' = 1$, so that $p' = nN \pm 1$ is always satisfied in a symmetrical N-phase lap winding.

Further, in a symmetrical lap winding, $S' = S/p$ (Equation 9), hence to obtain a symmetrical N-phase winding, $S'/N = S/(pN)$ must be a whole number, or the number of slots

$$S = N p n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

This condition for 3-, 4-, and 6-phase lap windings is entered in Table 2.

Though this condition is apparently so simple, it is easy to leave it unsatisfied by ignoring it. For example, if we have a rotary converter with $C/p = 96$ segments per pole-pair and $u = 6$ coil-sides per slot, we shall have $S/p = 2C/(pu) = 96/3 = 32$ slots per pole-pair. This is not exactly divisible by 6, so that the 6-phase pressure will not be symmetrical. With 2 or 4 segments per slot ($u = 4$ or 8), however, a symmetrical 6-phase pressure is obtained.

(*b*) *Symmetrical N-phase wave windings.*—With wave windings, both p' and S′ are subjected to restrictions when we require an N-phase system.

(i) *Number of poles.*—The only symmetrical wave windings from which a symmetrical N-phase system of pressures can be obtained are those where $p' = nN \pm 1$. These are shown in Table 1, and the impossible cases are denoted by a dash in Table 3. The same result can be obtained from the condition that S′/N must be integral, for obviously

$$\frac{S'}{N} = \frac{p'}{N} \cdot \frac{y_c}{C/S} \pm \frac{1}{N} \cdot \frac{1}{C/S}$$

can only be a whole number when p' and N have no common factor greater than unity.

(ii) *Number of slots.*—To find what numbers of slots in a symmetrical winding are exactly divisible by N, we can re-write Equation (11) for S′ thus:

$$S' = p' n \pm K = p' n' \pm (p' n'' \pm K),$$

where $n = n' \pm n''$. Let n' and n'' be chosen so that $n' = n''' N$ and $p' n'' \pm K = kN$, where n''' and k are whole numbers. We can then write Equation (11) in the form

$$S' = p' N n''' \pm kN = p' N n \pm kN,$$

where $S'/N = p' n \pm k$ is clearly a whole number (n''', being merely a number, can be replaced by n). In this way we get the values of S′ which are divisible by N, and for the total number of slots we have

$$S = a S' = a p' N n \pm a k N \quad . \quad . \quad . \quad (13)$$

In this equation, then, $kN = p' n'' \pm K$ is merely a value of S′ divisible by N. For the sake of convenience, we shall always take kN as the lowest value of S′ divisible by N.

To show how the values of S for N = 3, 4, and 6 are obtained in Table 3, we can work out an example. Let $p' = 3$, $a = 3$, and $N = 4$. For $p' = 3$ we see $S' = 3n \pm 1$, and the lowest value of this divisible by N is $kN = 3 \times 1 \pm 1 = 4$. Hence the numbers of slots that can be used in a symmetrical 4-phase wave winding with $p' = 3$ and $a = 3$ are

$$S = a p' N n \pm a k N = 3 \times 3 \times 4 n \pm 3 \times 4 = 36 n \pm 12.$$

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible] in Machine	[illegible]			[illegible]	[illegible]
					[illegible]	[illegible]	[illegible]		
1	[illegible]	f	f	f n	3 f n	4 f n	6 f n	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
						[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1 f	1 f	n f n	3 n 3 f n	4 n 4 f n	6 n 6 f n
2	2 n ± 1	2, 6, 10, 14	1 2 3 4 5 6	2 4 6 8 10 12	2 n ± 1 4 n ± 2 6 n ± 3 8 n ± 4 10 n ± 5 12 n ± 6	6 n ± 3 12 n ± 6 18 n ± 9 24 n ± 12 30 n ± 15 36 n ± 18	— — — — — —	— — — — — —
3	3 n ± 1	2, 4, 8, 10, 14, 16	1 2 3 4	3 6 9 12	3 n ± 1 6 n ± 2 9 n ± 3 12 n ± 4	— — — —	12 n ± 4 24 n ± 8 36 n ± 12 48 n ± 16	— — — —
4	4 n ± 1	2, 6, 10, 14	1 2 3	4 8 12	4 n ± 1 8 n ± 2 12 n ± 3	12 n ± 3 24 n ± 6 36 n ± 9	— — —	— — —
5	5 n ± 1 5 n ± 2	2, 8, 12 4, 6, 14, 16	1 2 1 2	5 10 5 10	5 n ± 1 10 n ± 2 5 n ± 2 10 n ± 4	15 n ± [illegible] 30 n ± [illegible] 15 n ± 3 30 n ± [illegible]	20 n ± 4 40 n ± 8 20 n ± 8 40 n ± 16	30 n ± 6 60 n ± 12 30 n ± 12 60 n ± 24
6	6 n ± 1	2, 10, 14	1 2	6 12	6 n ± 1 12 n ± 2	— —	— —	— —
7	7 n ± 1 7 n ± 2 7 n ± 3	2, 12, 16 6, 8 4, 10	1 1 1	7 7 7	7 n ± 1 7 n ± 2 7 n ± 3	21 n ± [illegible] 21 n ± [illegible] 21 n ± [illegible]	28 n ± [illegible] 28 n ± [illegible] 28 n ± [illegible]	42 n ± 6 42 n ± 12 42 n ± 18
8	8 n ± 1 8 n ± 3	2, 14 6, 10	1 1	8 8	8 n ± 1 8 n ± 3	24 n ± [illegible] 24 n ± [illegible]	— —	— —
9	9 n ± 1 9 n ± 2 9 n ± 4	[illegible] 16 8, 10 4, 14	1 1 1	9 9 9	9 n ± 1 9 n ± 2 9 n ± 4	— — —	36 n ± [illegible] 36 n ± [illegible] 36 n ± [illegible]	— — —
10	10 n ± 1 10 n ± 3	2 6, 14	1 1	10 10	10 n ± 1 10 n ± 3	30 n ± [illegible] 30 n ± [illegible]	— —	— —
11	11 n ± 1 11 n ± 2 11 n ± 3 11 n ± 4 11 n ± 5	2 10, 12 8, 14 6, 16 4	1 1 1 1 1	11 11 11 11 11	11 n ± 1 11 n ± 2 11 n ± 3 11 n ± 4 11 n ± 5	[illegible] [illegible] 33 n ± 3 [illegible] [illegible]	44 n ± [illegible] 44 n ± [illegible] 44 n ± [illegible] 44 n ± [illegible] 44 n ± [illegible]	66 n ± 12 66 n ± 24 66 n ± [illegible] 66 n ± 18 66 n ± 6
12	12 n ± 1 12 n ± 5	2 10, 14	1 1	12 12	12 n ± 1 12 n ± 5	— —	— —	— —

[illegible]

[illegible]

Attention may be drawn to the fact that, despite the restrictions on the number of poles, it is possible to obtain a symmetrical N-phase winding in most cases, though a modification in the design may be necessary. Thus, when a static balancer is to be used it is more important to have the N phases symmetrical than to insist on making $\mathrm{N}=3$ or $\mathrm{N}=4$. Consequently with a 4-pole wave winding we ought to make $\mathrm{N}=3$; whilst with a 6-pole winding we should make $\mathrm{N}=4$. When it is important to obtain a symmetrical N-phase winding on a machine with a large number of poles, it is often essential to alter the number of poles; for example, with $p=6$, we can do nothing, but by making $p=5$ or 7, we can get symmetrical 3-, 4-, or 6-phase pressures.

Similarly, it is necessary to select the number of coil-sides per slot suitably to make the N phases symmetrical.

In practice, p, a, and N, are known, whilst an approximate idea of the number of coils or segments is obtained from the preliminary design of the machine. Table 3 then shows the numbers of coil-sides per slot that are permissible, whence the value of S giving $\mathrm{C}=\frac{1}{2}u\,\mathrm{S}$ nearest to the approximate figure can be determined.

If a wave winding is closed, as it is when used with a commutator, the phases are obtained by means of tappings connected to slip-rings. When "polygon" loading is used, the phase-spread, $\sigma=\beta=2\pi/\mathrm{N}$; but by doubling the number of tappings and loading them diametrally, the output is increased to the same extent as when the phase-spread of an open winding is halved. Diametral loading, however, calls for no special treatment, for the tappings are merely taken to correspond. Thus, for a 3-phase diametral load we need to take the same tappings as for a 6-phase polygon load.

When a wave winding is not used with a commutator, as in the case of alternators and induction motors, the phases should be given the narrow phase-spread. This is done by opening the winding for 2 N phases and reconnecting the phases to form an N-phase winding, as explained earlier in this section and illustrated in the following examples:—

(V) *Location of Tappings and Openings.*

(*a*) *Tappings off symmetrical lap or wave windings.*—When $\mathrm{S}/a\,\mathrm{N}$ is an integer in any symmetrical lap or wave winding, a symmetrical N-phase system of pressures can be derived from it, and the points to be tapped for the phases can be written down at once after determining the potential-pitch, $y_p=\mathrm{C}/a$ segments, and the phase-pitch, $y_{ph}=\mathrm{C}/a\,\mathrm{N}$ segments. This is simply due to the fact that this is the only way of dividing the C segments into $a\,\mathrm{N}$ equal parts. Then we have,

$$\left.\begin{array}{l}
\text{Phase I taps segments or joints} \\
\qquad 1;\ 1+y_p;\ 1+2y_p;\ \ldots\ 1+(a-1)y_p \\
\text{Phase II taps segments or joints} \\
\qquad 1+y_{ph};\ 1+y_p+y_{ph};\ 1+2y_p+y_{ph};\ldots 1+(a-1)y_p+y_{ph} \\
\text{Phase III taps segments or joints} \\
\qquad 1+2y_{ph};\ 1+y_p+2y_{ph};\ 1+2y_p+2y_{ph};\ldots \\
\qquad\qquad 1+(a-1)y_p+2y_{ph} \\
\cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \\
\text{Phase N taps segments or joints} \\
1+(\mathrm{N}-1)y_{ph};\ 1+y_p+(\mathrm{N}-1)y_{ph};\ 1+2y_p+(\mathrm{N}-1)y_{ph};\ldots \\
\qquad\qquad 1+(a-1)y_p+(\mathrm{N}-1)y_{ph}
\end{array}\right\} \quad (14)$$

In windings with one turn per coil, the tappings can be taken equally well off the back of the winding, and this is usually done in practice for convenience.

Examples of the use of these equations will be found below.

(*b*) *Opened wave windings.*—In many alternators and induction motors it is necessary or desirable to have a fractional number of slots per pole and phase, when the number of conductors per slot is small or when it is desired to suppress ripples. This is a simple matter with the double-layer winding, and for this purpose the common wave winding ($a=1$) is eminently suitable. It is always best, wherever possible, to design the winding for 2 N phases, open it, and join each pair of opposite phases in series or parallel in order to reduce the phase-spread and so obtain the increase in output, due to the higher winding factor. The important case is the 3-phase winding, although a 2-phase winding is occasionally obtained in this way. The number of coil-sides per slot with an opened wave winding seldom exceeds 8, and is usually 4 or 6.

When $a=1$ (as Table 3 shows), it is only possible to get a symmetrical 6-phase system of pressures with machines having 2, 10, 14, and 22 poles, which are of little practical importance, although u is little restricted in these cases. It is possible, however, to get a symmetrical 3-phase system for all numbers of poles not a multiple of 3, and we shall show how the narrow phase-spread can be obtained by evolving the symmetrical 3-phase winding from an unsymmetrical 6-phase winding, a result which enables us to use the common series connection. With $a=1$, and $\mathrm{N}=3$, however, it is seldom possible to make $u=4$. The parallel connection is also possible by making a wave winding with $a=2$, which gives two like parts.

These various points can best be illustrated by means of the following examples.

(*c*) *Illustrative examples.*—To illustrate the points discussed in this section we shall now work out a few typical examples to show how to locate the points where a winding is to be opened or tapped for phases.

Example 1.—A 12-pole lap winding has 432 coils and 6 coil-sides per slot. Find the tappings for 3-phase diametral loading: $p=a=6$; $\mathrm{C}=432$; $u=6$; and therefore $\mathrm{S}=2\,\mathrm{C}/u=144$.

In order to get 3-phase diametral loading, we must find tappings for 6-phase polygon loading. The potential-pitch, $y_p=\mathrm{C}/a=\mathrm{C}/p=432/6=72$ coils, and the phase-pitch, $y_{ph}=\mathrm{C}\,a\,\mathrm{N}=\mathrm{C}/p\,\mathrm{N}=72/6=12$ coils. We can now write down the segments to be tapped, in accordance with Equation (14).

Slip-ring.

I taps segments or joints:	1	73	145	217	289	361
II ,, ,, ,,	13	85	157	229	301	373
III ,, ,, ,,	25	97	169	241	313	385
IV ,, ,, ,,	37	109	181	253	325	397
V ,, ,, ,,	49	121	193	265	337	409
VI ,, ,, ,,	61	133	205	277	349	421

For the diametral load, the phases A, B, C are taken between the rings thus:—

Phase A between slip-rings I and IV.
,, B ,, ,, III ,, VI.
,, C ,, ,, V ,, II.

[illegible] is an integer [illegible]

[illegible] Find

[illegible]
(β) Tappings for 3-phase diametral load;
[illegible]

[illegible]

The phase-pitch $y_{p6} = C/a N = 144/6 = 24$ coils, or [illegible] metrical 6-phase winding, each phase containing 24 coils, the successive phases being 12 slot-pitches apart. The joints or segments to be tapped can be written down at [illegible]

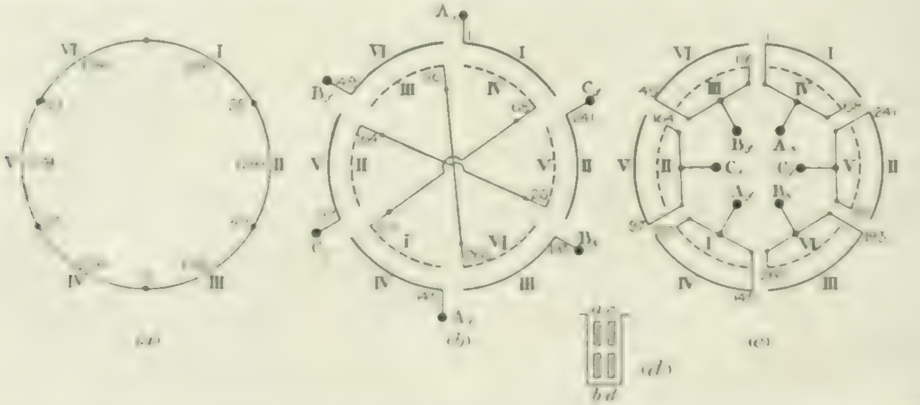
Phase	I	II	III	IV	V	VI
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1	[illegible]	[illegible]	73	[illegible]	121

If the vector polygon for the C coils is drawn, it will be seen at once that these are the numbers that divide the [illegible]

the 6 points where it is tapped for a 6-phase system, and phases x and $x + \frac{1}{2}$ N joined in series or parallel as desired. We can represent the vector polygon of the winding by the simple circle (*a*) and the winding itself by (*b*) and (*c*) as in Fig. 7. The joints to be opened corresponding with the vectors marked on the polygon are shown in the table, along with the positions of the coil-sides in the slots (see (*d*), Fig. 9).

[illegible]	[illegible]	[illegible]	[illegible]
1	1	1 in slot 1	[illegible]
[illegible]	121	[illegible]	212 [illegible]
49	97	[illegible]	[illegible] 41
73	73	[illegible] " " 37	116 [illegible]
97	[illegible]	[illegible] 25	[illegible]
121	[illegible]	[illegible]	[illegible]

In the above table it is noticed that the numbers of the vectors are the same as the numbers of the joints they represent. Obviously this must always be the case when C is exactly divisible by N, though the cyclic order, of course, may be different.



[illegible]

[illegible]

Phase	A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	I	II	III	IV	V	VI
[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Since the slot-pitch is 25°, it will be seen from the position of the coil-side in the slots that, from A, to B, is [illegible] useful value between 2 and 3.

[illegible]

[illegible] load.

[illegible]

We have $p=2$; $a=1$; $C=135$; $u=6$; and $S=45$. Therefore the commutator-pitch $y_c=(C\pm 1)/p=\frac{1}{2}(135\pm 1)=68$ or 67. Take $y_c=y_b=y_f=67$.

(*a*) *Tappings off closed winding for 3-phase polygon load.*—Since $S=6n\pm 3=6\times 7\pm 3=45$ (Table 3), the phase-pitches $C/(aN)=135/3=45$ coils, and $S/(aN)=45/3=15$ slots, are whole numbers, so that it is possible to get a symmetrical 3-phase system of pressures from the winding. The segments to be tapped are then:

Phase ...	A	B	C
Segment tapped	1;	$1+y_{ph}=1+45=46$;	$1+2y_{ph}=46+45=91$

In the vector diagram in Fig. 10 it is seen that the three vectors with these numbers are 120° apart.

It is clearly not possible to obtain a symmetrical 3-phase system from this winding by diametrical loading, since C/a is not divisible by 6.

(β) *Openings for symmetrical 3-phase winding with phase-spread of* 60° (Fig. 10).—In Example 2 we obtained a symmetrical 3-phase winding with $\sigma=\frac{1}{2}\beta=60°$, from a symmetrical 6-phase winding. Table 3 shows it is seldom possible to obtain a symmetrical 6-phase system; but, unless p' is a multiple of 3, an unsymmetrical 6-phase system can be obtained which will give a symmetrical 3-phase system when the unequal phases x and $x+\frac{1}{2}N$ are joined in series. The parallel connection is inadmissible, since opposite phases are dissimilar. The present winding is a case in point. We have $C/(aN)=135/6=22\frac{1}{2}$; and hence we take the 6 phases containing 23 and 22 coils alternately, as shown in Fig. 10, and draw up the following table:—

Vector No x	Joint No. $b=1+(x-1)y_c$	Top Coil-side $2b-1$	Bottom Coil-side $(2b-1)-y_f$
1	1	1 *a* in slot 1	204 *f* in slot 34
24	57	113 *e* ,, 19	46 *d* ,, 8
46	46	91 *a* ,, 16	24 *f* ,, 4
69	102	203 *c* ,, 34	136 *d* ,, 23
91	91	181 *a* ,, 31	114 *f* ,, 19
114	12	23 *c* ,, 4	226 *d* ,, 38

The slot-pitch is $p\times 360/S=2\times 360/45=16$ electrical degrees. Hence the phase displacement between A_s and B_s is 15 slot-pitches $=240°$, and between A_s and C_s 30 slot-pitches $=480°=120°$. Thus A_s, B_s, and C_s are at 120°, and we shall find that A_f, B_f, and C_f are at 120° also. Thus by placing phases I and IV, III and VI, and V and II, in series, we shall get the symmetrical 3-phase system A, B, C. In this example $q=45/(4\times 3)=3.75$ slots per pole and phase.

Example 4.—A wave winding with $a=2$ has 8 poles, 342 coils, and 6 coil-sides per slot. Find

(α) Tappings off closed winding for 3-phase polygon load.
(β) Openings for symmmetrical 3-phase winding with phase-spread of 60°.

In this case $p=4$, $a=2$, $C=342$, $u=6$, and $S=114$. Hence the commutator-pitch, $y_c=\frac{C\pm a}{p}=\frac{342\pm 2}{4}=86$ or 85. Take $y_c=y_b=y_f=85$.

(*a*) *Tappings off closed winding for 3-phase polygon load.*—Since $S=12n\pm 6=12\times 10-6=114$ (Table 3), the phase-pitch is $C/(aN)=342/(2\times 3)=57$ coils or $S/(aN)=114/(2\times 3)=19$ slots. Both these are integers, showing that it is possible to obtain a 3-phase symmetrical system by polygon loading. The potential-pitch, $y_p=C/a=342/2=171$. The segments to be tapped are then written down from Equation (14) thus:—

Phase	taps segments or joints:
I	1 and 172
II ,, ,, ,,	58 ,, 229
III ,, ,, ,,	115 ,, 286

(β) *Openings for symmetrical 3-phase winding with phase-spread of* 60° (Fig. 11).—We can now open the winding and get a 3-phase system by a method similar to that used in the last example. This case is often very useful, as the two parts of the windings are alike and can be put in parallel—a connection which cannot be employed with common wave windings when the phases x and $x+\frac{1}{2}N$ are unequal. Thus by making $a=2$ we can overcome the restriction met with in Example 3. The diagrams and table are drawn up below, each set of 57 coils being divided into 29 and 28 alternately.

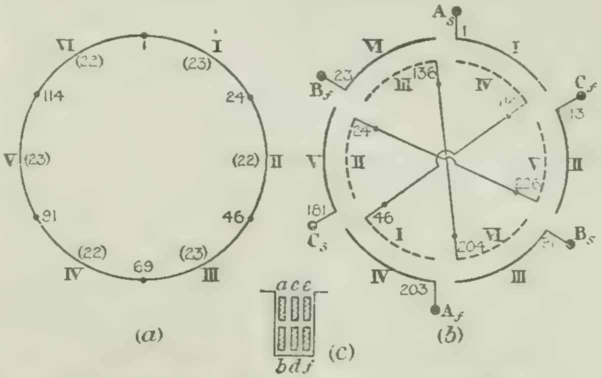


FIG. 10.—Unsymmetrical 6-phase wave winding with $a=1$, opened to give a symmetrical 3-phase winding with narrow (60°) phase-spread. (Suitable for series connection only.)

(*a*) Vector polygon. (*b*) Series connection.
(*c*) Numbering of coil-sides in a slot.

Vector No x	Joint No. $b=1+(x-1)y_c$	Top Coil-side $2b-1$	Bottom Coil-side $(2b-1)-y_f$
1	1	1 *a* in 1	600 *f* in 100
30	72	143 *e* ,, 24	58 *d* ,, 10
58	58	115 *a* ,, 20	30 *f* ,, 5
87	129	257 *e* ,, 43	172 *d* ,, 29
115	115	229 *a* ,, 39	144 *f* ,, 24
144	186	371 *e* ,, 62	286 *d* ,, 48
172	172	343 *a* in 58	258 *f* in 43
201	243	485 *e* ,, 81	400 *d* ,, 67
229	229	457 *a* ,, 77	372 *f* ,, 62
258	300	599 *e* ,, 100	514 *d* ,, 86
286	286	571 *a* ,, 96	486 *f* ,, 81
315	15	29 *e* ,, 5	628 *d* ,, 105

It will be seen that the starts or the finishes of successive [illegible] In this way [illegible]

[illegible] per pole [illegible]

The above examples will be sufficient to show the great [illegible] N-phase system [illegible] windings with a fractional number of slots per pole. These are of immense importance in alternating-current machines.

(VI) Wave Windings with a Whole Number of Slots per Pole.

A double-layer winding which finds frequent use in practice is the wave winding with a whole number of slots per pole, or per pole and phase, as the case may be. In this winding, the pitch between successive coils is not uniform, as in the ordinary wave winding, connected up in accordance with Equation (8). The coil-span is usually made equal to a pole-pitch, likewise the pitch between successive coils, and after every p coils, i.e. after each tour of the periphery, the pitch is shortened or lengthened to miss the place already occupied.

Though the slotting is suitable for obtaining a number of similar parallel circuits, this form of wave connection is mostly used where only one circuit per phase is needed. For alternators and induction motors with 2, 4, 6, or 8 coil-sides per slot this type of winding has many advantages over the equivalent single-layer winding, but the pronounced spacing and tooth ripples, which are always possible with a whole number of slots per pole, are not affected thereby. In other words, the use of wave connectors with a whole number of slots per pole does not make the winding in any way equivalent to a winding with a fractional number of slots per pole.

By joining all the coils in the winding in series in this way, we get a winding distributed uniformly over the circumference and in which the sum of the induced pressures is zero. Consequently the start and finish can be joined together to form a closed winding, from which a mesh-connected polyphase system can be obtained. In this way the slotting for a lap winding can be used for a wave winding, but here again it must be remembered that we may get pronounced ripples in the pressure curve.

This paper was written at the City and Guilds (Engineering) College, South Kensington, and the author has to acknowledge his indebtedness to many friends for valuable help and criticism. Mr. B. Hague, B.Sc., a post-graduate student in electrical engineering, made the diagrams and gave much assistance in compiling and checking the results. The work on Table 3 was partly begun in 1912-13 when Mr. S. J. Symms collaborated with the author in an investigation on symmetrical wave windings. The author's thanks are due to Professor Miles Walker, Mr. C. C. Hawkins, Mr. R. G. Jakeman, Mr. J. W. Sims, and Mr. J. T. Irwin for reading the manuscript and making many useful suggestions.

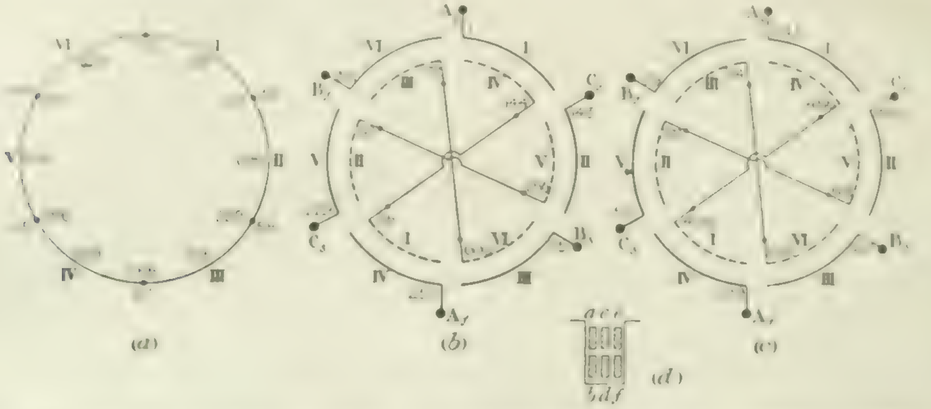


Fig. [illegible] 6-phase wave winding with [illegible] 2, opened to give a symmetrical 3-phase winding with narrow (60°) phase-spread. (Suitable for series or parallel connection.)
[illegible] polyphase systems. (d) Numbering of [illegible] in a slot.

WESTERN LOCAL SECTION: CHAIRMAN'S ADDRESS,

By Professor DAVID ROBERTSON, D.Sc., Member.

(Address delivered at Bristol, 23 October, 1916.)

When this address first began to loom in the distant future, it was my intention to speak a few words to you on the subject of research, but in the interval so much has been written about it that the wind has been taken out of my sails and little room has been left for anything fresh to be said on my part.

In the past our industries were able to take a leading position in the world, but now our position is neither so good nor so secure as it was. In comparison with our competitors, do we now produce fewer men of genius than formerly, or does our relatively worse position arise from our making less use of them under the changed conditions?

A century ago the inventive genius, of itself, had a fairly free scope, but in the industrial world of the present day it must be coupled with a much higher degree of scientific knowledge and technical training, and have behind it much greater material resources than formerly if it is to make its influence felt. In the early days of industry the problems to be solved were mainly mechanical, speeds were low, the choice of materials was comparatively small, and the duties put upon them were moderate, while prices were high enough to permit the use of sufficient material to give a good big factor of safety. Only the simplest calculations had to be made, and little scientific knowledge was necessary beyond that acquired in the daily routine of the shops. Consequently, many important advances were made by men having but the slightest theoretical knowledge.

Nowadays, competition requires the utmost to be got out of each ounce of material; higher speeds may cause extra material to be a source of weakness rather than of strength and introduce phenomena the control of which requires the keenest tools that theory can supply. The advent of electrical transmission has brought into being an entirely new branch of engineering, ever extending its bounds, involving enormously more theoretical knowledge than the older branches, and requiring, in addition, a clearer insight into abstract things. On all hands, calculations must be more exact, and side issues of little importance in the old days have now to be closely taken into account.

The field of knowledge may be likened unto a gold field. The first comers acquire the surface veins and nuggets with comparative ease and with the crudest equipment; but as these become exhausted their successors must expend more and more preliminary labour without immediate result, and they must possess more and more knowledge if these labours are not to prove altogether fruitless.

In the field of research we are now far past the first stage. The surface treasures which Nature has placed to tempt our further search have mostly been harvested and the investigator must now be prepared to undergo a long preliminary training before his work is likely to become productive. Consequently, he must have behind him resources sufficiently great to support him during this non-productive period and to provide the ever-increasing apparatus and materials necessary for carrying on his work.

We have every reason to be proud of the advances made, and being made, by our own countrymen in the domain of science, but at the same time I do not think we put into this work a sufficient number of men of the right sort, of the right training, and of the right temperament. Further, *I do not believe we shall ever get them until we offer them prospects comparable with those open to other professional careers.* It is not sufficient to depend alone on the favoured few whose circumstances enable them to pursue their own ideas without having to worry about the cost or about their bread and butter. To keep up the prosperity of our country we must put the best brains from all classes to those tasks which are most likely to increase the common good.

Let us put ourselves in the position of the father of a boy at school about to determine what his career shall be. If he decides on a classical one and the boy is smart, he can see before him a long vista of highly lucrative posts as an advocate, judge, government official, or administrator in some business or professional capacity. On the other hand, if he considers science he can see little scope beyond a very few well-paid professorships, rather more fairly-paid lectureships, and a host of other teaching posts which besides being underpaid leave but little time for the research work we have in view. A few advanced firms do think it worth while really to pay a scientific worker, but only the fortunate few of those who try to find a market for their scientific knowledge in commercial concerns get much past the stage of a routine tester at a miserable pittance per week. If he is specially lucky he may, for instance, become a charge chemist in a factory under a Government sufficiently enlightened to value his services at just less than those of the labourers whom he directs.

What wonder then if the majority of our best youths have their bent directed away from science into what I might call the verbal professions.

I repeat, therefore, that if our scientific output is to be increased in volume up to our needs and to be maintained at the high level set by our masters of the past, *our first step must be taken at the source by seeing that the scientific career is made sufficiently attractive, in competition with the other professions, to induce a sufficient number of our very best youths to pursue it.*

The scientific side at school must be rescued from the opprobious name of "stinks" and must have equal prestige with the classical. The scientific man must be as greatly respected by the public at large, and must be as [illegible] to any [illegible] He who [illegible] new light for our guidance in the future deserves as much kudos from his fellows as one who is full of the precedents of the past, and is certainly more worthy than another whose sole claim to fame arises from his assistance to one of the great political parties in gaining or retaining a parliamentary vote for their own particular shibboleth.

Although legislation can help but little in raising science to its rightful status, still it can do something. It might, for instance, encourage the study of science in our public schools by insisting on a certain minimum of scientific knowledge in future generations of public officials. It would be unreasonable to ask these to become scientific experts, but a knowledge of scientific thought would enable them to recognize a problem calling for expert assistance, to appreciate the arguments of the expert, and to assist him by suggestions arising from their experience of the conditions surrounding the problem. It would also make them more open to receive new ideas and so would very materially ease the paths of progress. Even in purely administrative branches such a spirit could scarcely fail to lead to increased efficiency.

Another thing which the Government could do is to make the value and number of the scholarships open to the science boy somewhere about level with those given for classical studies. This could be done either by a special Act diverting part of the present scholarship funds or by the Government themselves founding a sufficient number of new scholarships. Our best schools cannot be dragooned into giving a large place to science against their wish, but they are not altogether insensitive to the claims of the particular examinations which their boys must pass in order to take up their professional career.

By thus making the way to a large number of the lucrative positions lie through a study of science, we should very quickly find every school running a real scientific side, and our universities would then be able to pass away from the condition of having to make their scientific alumni pass their first year in learning elementary work which they ought to have done at school.

We must, however, mainly look to our own men of eminence to bring about a better state of things by continually keeping the needs of science before the proper influential quarters. The war has focussed attention on scientific work with an entirely new force. Never again must public opinion be allowed to forget how much they owe to the often-times obscure worker in the research laboratory. In particular, our leading men must see that their magnificent rally to the assistance of a Government whose "neglect of science" has been their perpetual lament, shall not be misconstrued by the politician and official and confirm their notion that scientific men are merely theorists whose ideas can usually be neglected and [illegible] be obtained, on those rare occasions when it is useful, without any reward and indeed almost without the trouble [illegible]

[illegible] appreciate the value of their services, and the only way to [illegible] these times the "patriotic" politician himself insists on his price before agreeing to some re-arrangement which has become desirable in the national interests, while those who in other lines work for the country "on the basis of pure patriotism" seem to grow wondrous fat in the process. In fact, if we are to judge by the actual payments made by the Government, a single buyer of timber or contractor for army huts is worth far more to the country than several universities of scientific men.

One of the great difficulties in the way of scientific men reaping the due reward of their labours arises from the fact that the benefits of their discoveries are seldom immediately tangible, while at the same time they are open to the whole of mankind. What reward, for instance, did Faraday reap from the discovery of the electric motor and generator; Clerk Maxwell and Hertz from radio-telegraphy; or Ramsay, Rayleigh, and Dewar from the gas-filled lamp? True, none of these things were invented, in a commercial form at least, by these particular men, but their work opened up the new ground which made the inventions possible.

Because of this peculiarity, the highest kind of research work must be supported by mankind at large, which in this country means Parliament and the Exchequer.

The true research worker must possess an infinite patience, a fertile imagination, a wide knowledge of the laws of Nature, and an unbounded faith in the possibility of accomplishing the task on which he is engaged. He must refuse to be diverted from his goal by any reputed impossibility, and if necessary he must be prepared to overthrow accepted ideas when they stand in his way. *[illegible] of his fellows.* In [illegible] Bremer improved the arc light by doing exactly what every one would have said was the wrong thing; before Marconi's experiments in 1901 it was perfectly easy to demonstrate that transatlantic radio-telegraphy must for ever be impossible; in 1910 Coolidge succeeded in drawing tungsten into the finest wires that were ever made in spite of the knowledge among the experts that this metal was far too brittle to be even forged into a rod; in 1913 Langmuir produced the gas-filled lamp when we all knew perfectly well that the best possible vacuum was absolutely necessary for an efficient lamp.

And so it will always be. He is not worthy of the name of pioneer who regards even the laws of gravitation, and of the conservation of energy, mass, and momentum as dogmas which may not be attacked and overthrown when they block his way.

Research is best dealt with in bulk, so that workers in different fields may come into daily intimate contact. A man with a new idea will develop it more rapidly and carry it further if he discusses it over a pipe with a fellow spirit even although the latter can do no more than listen to the exposition. If the subject borders on his own in any way, the cross-fertilization of the sciences produced by such a discussion may lead to enormous results.

The research worker, however, must also come into close touch with the industrial side of his own subject, without devoting so much time to it that real research gets squeezed out altogether. The man in the factory meets many problems for the solution of which he possesses neither the time nor the knowledge. The scientific man, however willing and competent he may be, would never meet these problems by himself. Keep these two men apart and the problem remains for ever unsolved ; but bring their experiences together and progress is sure to follow.

For the success of this co-operation, mutual respect and confidence are required between the manufacturing and scientific sides of industry. This co-operation has been greatly developed with marvellous results in several directions in America, where its realization has been facilitated by the aggregation of capital into huge trusts. Except in a few of our industries, it is scarcely practical to have that continuous intercourse betweeen the research worker and the factory which is obtained in the well-known American examples, with their real research laboratories attached to, or closely affiliated with, the productive departments. But to some extent the difficulty can be overcome by insisting that the research workers should periodically spend some time in the factory. The duration of these periods must depend on the nature of the work on hand, but they should be as frequent as possible. Even if they amounted to nothing more than a weekly visit to the shops and chats with the managers and foremen, the results would be good, provided that the men in the works did actually discuss their difficulties and give the scientific men the benefit of their own knowledge.

Trade secrets, or supposed trade secrets, stand in the way of that goodwill on the manufacturer's part without which no such scheme can be really useful. But we must either overcome these difficulties, or else we must organize our industries into corporations large enough to bear the expense of huge research departments directed to their own particular ends. Otherwise, we shall in time lose our industries altogether in favour of other countries who may have succeeded in doing one of these things.

Each industry has its own problems which are more or less recognized by those engaged in it. We could all write out lists of what we think we most want in our own sphere ; but I wish to direct your attention to one rather big problem of the utmost importance for the future welfare of our own country. I refer to our supply of energy. Past ages have placed vast stores to our credit in the great "Coal Bank," but as we are drawing our cheques upon it with ever-increasing prodigality and nothing is now being paid into it, sooner or later we shall find our cheques returned marked "no funds." It will not occur in our time, but historically speaking the exhaustion of our coal supplies is not remote. It seems fairly certain to come within three centuries, and may even occur within one.

If our country is not to decline into a very inferior position by that time, we must, in the interval, either discover new sources upon which we can draw, or else we must contrive to live within our income.

Our annual consumption of coal is about 200 million tons per annum. Since the energy of one ton of coal is almost exactly one kilowatt-year, we are drawing on our energy capital at the rate of about 200 million kilowatts.

We have, of course, other sources of energy of which we are aware, and possibly many others still unknown. The energy of disintegration of the atoms is enormous ; when this is brought under our control we shall have an ample supply for a few ages more, and may even be able to ward off the approach of the next ice age which is due in some thousands of years.

Another large store of energy, mainly derived from the kinetic energy of rotation of the earth, is made available to us through the tides. To raise the level of one square mile of sea by one foot involves the expenditure of about 340 kilowatt-hours. Under ideal conditions of admitting all the water at high tide and releasing it again at low tide, this amount of energy would be available each half tide of, say, 6½ hours. The tidal power is thus equivalent to about 55 kw. per square mile per $(\text{foot rise})^2$. Ideal conditions could not be realized, and there would be losses in the turbines, and so we probably err on the high side if we take 10 kw. per square mile per $(\text{foot rise})^2$ as the maximum we might expect to be able to utilize. This would give 10,000 kw. per square mile with a double tidal amplitude of 31·5 feet, and 500 kw. for one of 7 feet.

The Bristol Channel is by far the most favourable place in this country for the large-scale utilization of the tides, and I think the Firth of Clyde stands next because of the large area which could be enclosed within a comparatively short dam. We shall not be far out if we take 10,000 kw. per square mile as applicable to the first and 500 kw. to the second of these areas.

A dam across the Bristol Channel from Brean Down to Lavernock Point, taking the Flat Holm on the way, would be under 8 miles in length. It would enclose well over 100 square miles of water, and would give, say, a million kilowatts. One built across below Ilfracombe would be nearly 30 miles long, would enclose quite 10 times as much, and might be expected to give us about 10 million kilowatts.

The only possible place for a dam across the Firth of Clyde is the shallow bar somewhere near the Girvan–Kintyre line. It would be in somewhat deeper water than the Bristol Channel ones, would be just over 30 miles long, and would enclose much about the same area as the lower Channel one ; but owing to the much smaller tides it would probably give us no more than half a million kilowatts.

I have no doubt that the modern engineer could construct any of these dams within a reasonable time if he were provided with sufficient funds. The capital costs would be very high ; I do not know what they would be, but I do not expect that power obtained in that way could compete with our ordinary methods so long as a plentiful supply of coal lasts. Stated in kilowatts they do seem enormous sources of power, but compared with the equivalent of the coal supply which will some day have to be replaced they are quite insignificant. We have, of course, other estuaries which could all be made to contribute their quota, but when all are harnessed I think we shall still be very far short of the equivalent of our present consumption of coal.

With the power available in the electrical form, many economies would be made, but we must remember that our requirements are going up by leaps and bounds and that these increases would almost certainly exceed the savings from a more efficient use. I therefore think we may conclude that the tides will never do more than replace a quite small part of our coal consumption.

We must now turn our attention to the consideration of our income, which is paid out to us day by day from the sun. [illegible] as it falls on the earth's atmosphere is somewhere about 5 million kilowatts per square mile of normal surface, which would mean about 3 million kilowatts per square mile of land at our latitude at the equinox noon. Averaging it out throughout the 24 hours and throughout the year, we may call it a million kilowatts per square mile here. Over one-half of this, however, is absorbed by the atmosphere, but what is left is ample for our needs and we must find a method of turning it to our own ends before our coal supply is exhausted.

For the economical utilization of the sun's energy on a large scale it will be necessary to keep the size of the power house within reasonable dimensions, and to provide for keeping it running throughout the 24 hours. The direct application of the rays for driving a heat engine, which is quite practical on a small scale in tropical countries and has actually been done in Meadi in Egypt, would thus scarcely meet our needs even if our climate were suitable, which it is not.

Storage of the energy in some intermediate form is thus necessary to enable us to concentrate it and to level up the discrepancies between the curves of supply and demand.

Nature provides us with such storage in several forms. First we have gravitational energy in the shape of water raised from the oceans up into the clouds, and this has the especial merit that it makes some use of the areas covered by water. But the smallness of our island makes our share of this bountiful supply somewhat meagre, and consequently we must look to other forms unless some genius will show us how to collect the water high up in the clouds so that we can utilize the energy now wasted in atmospheric friction by the falling rain. Other countries are more favoured in this respect than ours, and every development of the electrical transmission and utilization of power increases the advantages which their industries consequently possess over ours.

The winds give another means of temporarily storing the energy received from the sun, partly in the kinetic form and partly in the compression of the air. Here, again, difficulties arise from the uncertainties of the winds, and from the enormous size which a large power windmill would have. Still, research must not dismiss anything as impossible. The rapid advances in the size of steam and water turbines and of electric generators should teach us not to dismiss wind-power as utterly hopeless.

The last form of storage which I shall consider is chemical energy, to which class indeed our coal itself belongs. The only way in which the solar energy is taken up chemically in Nature, so far as I am aware, is through the agency of plant life. *Failing other means, we must grow our fuel.* I therefore offer to our agriculturists the problem of producing a plant having a high calorific value, which shall utilize as high a proportion as possible of the energy falling on the areas devoted to its cultivation, and which shall be suitable for use as fuel, either directly or by distilling alcohol or other spirit from it.

At the same time I ask our electrochemists to find a method of taking up that energy electrically from the plant, or its products, without first converting it into heat, so as to avoid the large thermo-dynamic losses inherent in the heat engine.

Or better still, I ask our chemists to devise some reaction which will occur with the absorption of energy under the action of sunlight, and which can be reversed, under control, with the return of that energy in the electrical form. *In short, give us a storage battery which is charged by exposing [illegible] materials to sunlight and which is discharged in the ordinary way.*

As a last resource, in case these should fail, let our ultra-physicists combine with the biologists and produce between them a sufficient number of Maxwell's sorting demons to emancipate us from the second law of thermodynamics.

YORKSHIRE LOCAL SECTION: CHAIRMAN'S ADDRESS,

By H. A. NEVILL, Member.

(Address delivered at Leeds, 8 November, 1916.)

After consideration I decided to speak to-night on the question of the supply of coal and its economical use, only to find later that many abler men have all chosen the same subject; in fact, so many papers have been read that it practically impossible to avoid overlapping, but the importance of the subject must be my excuse for pursuing it.

The majority of the papers that I have had the opportunity of reading all emphasize the necessity for economy in the use of the country's fuel supply, but Mr. Arnold Lupton in his paper at Cardiff, before the South Wales Institute of Engineers, would seem to wish to convey the idea that there is very little cause to worry at all about fuel supplies. Mr. Lupton's proposal to supply the whole of the power required in the United Kingdom from the sun's heat in the Sahara Desert, is a wonderful scheme but unfortunately not a feasible one.

Since the commencement of the War one of the greatest troubles in connection with coal supply has been the diminished output of the collieries. This is largely due to the excellent way in which the miners have joined up, and I believe some 288,000 are to-day serving in His Majesty's Forces. These men will doubtless only be returned to their civil employment at a slow rate; many will unfortunately never return at all, having given up their lives for their country, and probably many others after their present experience of an open-air life will no longer be willing to work below ground. Under these circumstances a continued shortage of labour for some years is certain.

The labour difficulty is increased by absenteeism, the average loss of time for the whole of the United Kingdom being 9·9 per cent (see Coal Organization Committee Report), while so far as Yorkshire is concerned, I regret to say that it varies between 15 and 20 per cent. No overtime can be worked in collieries to recover this loss, owing to the provisions of the "Eight Hours" Act. Earnest representations are being made to the men and their leaders on the subject, and it is to be hoped that some action will be taken at an early date to remove this stigma from a class of men who have otherwise responded so well to their country's call.

The larger use of machinery, such as coal cutters, face conveyers, etc., would seem to be a possible solution of the labour difficulty. I am informed on good authority that 10 per cent per annum represents in round figures the present increase in this class of plant in the United Kingdom; in some districts, however, although machines are installed only indifferent use is made of them and production is not much helped in consequence. The greatest progress in the use of electrically-operated machines has been made in Scotland, owing to the working of thinner seams and greater freedom from gas. English collieries are steadily opening up thinner seams and will have considerably to extend their use of cutters and conveyers to enable them to deal with the difficulties of working.

The two sources of power used for underground machines are electricity and compressed air; of these, the former is much the better from the point of view of efficiency and the possibility of providing the largest amount of power for the space occupied.

In actual practice it is found that the efficiency of electrically-operated machines is as high as 70 per cent, while that of compressed-air operated plant is only 20 to 25 per cent. These figures are overall efficiencies including the generating plant or compressors, as the case may be. I know of one extreme case where an experiment in cutting a heading by compressed-air machines showed that eight times the energy was required compared with directly electrically-operated plant. In this particular instance the air supply was obtained from motor-driven compressors placed underground some little distance from where the cutting was being done, and the result was probably largely due to the low load factor of the system.

Another instance I know shows quite opposite results obtained by taking a 3,000-volt alternating-current supply down the pit to static transformers placed about 200 yards from the coal face, and from these operating electrical cutters at 200 volts.

Present-day legislation favours the use of compressed-air machines in preference to that of electrical ones, with the result that the more general use of machines is retarded due to the cost of operating such low-efficiency plant and also to the small amount of power available from the air-driven type. Experiments are now being made in the use of air-driven turbines for working coal cutters to try and increase their power, but it seems to me doubtful if this alteration would much improve the efficiency of the machines.

Considerable progress has been made in recent years in the design of electrically-operated coal cutters and in switchgear and cables, but if it is really necessary to impose the heavy restrictions on the use of electricity that are now in force, it would seem to be up to the electrical manufacturers to develop further improvements and to produce plant still better suited to the conditions.

The possibility of getting a greater percentage of the available coal has recently been largely considered, but it would seem that this is purely a matter of commercial balance between the cost of production and the selling price. Generally speaking, all coal is got that can be cut with safety and without prohibitive cost. No coal owner could be expected to work his mine at a loss, but, given a sufficiently high selling price or a cheaper system of working, more coal would be produced, even to the working of seams only two or three inches in thickness.

The present system of working underground provides first for the safety of the men, and this is quite as it should be, for the lives of the men are of a greater value to the country than the coal; but this safety can be secured only by temporarily sacrificing part of the coal or replacing it with expensive protective arrangements. In thick seams a part of the seam is left in order to provide a better and stronger roof; and the percentage depends on the nature of the material immediately above it and the tendency to "gob" fires. If this roof coal were removed, the extent of the propping would necessarily be heavily increased; particularly with the present price of timber and all other stores this could not be done without, as previously mentioned, increasing the pit-head price of coal. If by the greater use of efficient machinery, coal could be worked more quickly the roof difficulty might be reduced owing to the shorter period during which support would be required.

Summarizing the foregoing, it is my opinion that modified legislation dealing with the control of mines, particularly as relates to the use of electricity, together with more rapid development in the use of electrically-operated machinery below ground, would tend to solve to some extent the present and future difficulty in the sufficient production of fuel.

The possibilities of purchasing coal in the future at the prices ruling before the war seem very remote, and power station engineers will be compelled to look for their economies to the use of more efficient plant, to co-operation, or to more economical systems of coal consumption than direct combustion on a boiler grate.

The scheme recommended by the Board of Trade for the linking up of power stations is one that would aid in reducing the coal consumption per unit in those stations so favourably situated that they can adopt it. National coal economy was the reason for the recommendation being made, but the saving to be effected does not at first sight seem sufficient to warrant the very heavy expenditure which would be incurred in many cases in carrying it out.

In my opinion a great advantage that would arise from linking up would be increased continuity of supply. Interruptions to supply systems are much less frequent than in the past, and anything that will help in securing further reliability will also help in promoting confidence in the public supply systems in the mind of the general public. One of the reasons that has deterred many possible consumers from being converted in the past has been the possibility of interruption; the more that objection is removed, the faster will isolated power plants be scrapped in favour of purchasing energy from the public supply mains.

The centralization of power generation under skilled control cannot but lead to economy in fuel, and the greatest result will be obtained when the direct combustion of coal at innumerable scattered boiler installations and in the domestic fireplace is displaced by the use of electricity, gas, or a fuel from which the residuals have been extracted. I do not suggest that centralization should be carried out to such an extent that the whole country's requirements be supplied from one or two mammoth power stations, as I do not consider that economy lies that way. Moderate-sized stations suitably designed and placed to utilize waste heat, gas from carbonization plants, or other available sources of power, and linked together on a standardized system, would secure the most economical use of coal. The large industrial areas of the country, such as Yorkshire, Lancashire, the North-East Coast, etc., provide the greatest supplies of so-called waste heat and gas, and also naturally the greatest demand for energy, and it is in these areas that progress is already being made on the above lines.

There are many large towns the distance of which from their neighbours renders linking up at present prohibitive on account of cost; and where the local industries do not provide waste heat or gas in quantity it would seem quite feasible to combine with their power stations a modern plant for the carbonization of coal and the recovery of residuals before combustion.

I understand from my friends in the coal world that it is the supplies of best domestic coal that are first becoming exhausted, and consequently there will be an increasing demand for a good and cheap substitute. The lower-temperature carbonization processes produce a fuel highly suitable for domestic use and one that would greatly assist in reducing the smoke nuisance in heavily populated areas.

Many schemes are being evolved at the present time for the future benefit of our country, the majority of which would require considerable capital expenditure. To secure economy in coal usage also requires an initial outlay that would impose a heavy burden on electricity supply undertakings of the country if the money were raised in the usual way. The need for economy in fuel is a national one, and it would not therefore seem unreasonable to suggest that the Government should make some provision for granting easy terms for securing money to the electricity supply authorities. A small tax on exported coal would, without imposing an unduly heavy burden on the purchasers, provide for the greater portion of the necessary expenditure incurred in obtaining the desired result.

MANCHESTER LOCAL SECTION: CHAIRMAN'S ADDRESS.

By A. E. McKENZIE, Member.

(Abstract of address delivered 14 November, 1916.)

Another year has gone by and the opening of a new session still finds this country engaged in a life-and-death struggle. Many of our members have responded to the call to arms; some have unfortunately lost their lives, and those of us who are engaged on work at home essential to the carrying on of the world-war to a satisfactory conclusion must see to it that nothing we can do is left undone to help our country in this time of stress, and further to adopt all possible means whereby the British engineering industry can be placed on a better foundation than it ever was before.

ORGANIZATION OF ENGINEERING INDUSTRIES.

Much has been written in the daily Press, and in every technical journal, regarding the re-organization of British industries, and many Committees have been appointed by the Government to consider the case of particular industries. The Committee whose recommendations are awaited with great interest by electrical engineers is that one appointed by the Board of Trade to consider the electrical industry, and which is presided over by Sir Charles Parsons.

One Association alone which has been recently formed represents firms having an aggregate capital of over 150 millions sterling. Such a powerful Association cannot fail to bring considerable influence to bear in many directions upon the trading conditions of the Empire. Many of our largest electrical engineering firms have joined this Association, which of course is to devote itself to British industries generally. Other Associations have been formed solely for re-organizing the British engineering industry. We know that the six leading engineering societies of the German Empire have amalgamated expressly for the purpose of re-capturing their foreign trade which, through the invincible British Navy, has been cut off from them as it were by the stroke of a knife. It is the duty of each and every one of us to see to it that no effort is spared to prevent them re-capturing this trade. It has been abundantly proved that the engineering firms of this country can supply all our requirements, of equal if not better quality than our continental neighbours could supply, from a turbo-alternator to a lamp. If the purchasing engineers of this Empire, as distinct from those engaged in manufacturing, remember after the War the sentiments that most of us now feel, there is no doubt the British engineering industry will soon attain that position to which it is justly entitled.

This is not said to imply that British manufacturers have in the past done all that they should do to cater for the requirements of, say, the electrical engineering industry. To cite one case only, that of turbine rotor discs: we know that practically all these came from abroad before the War, mainly because the steel makers of this country would not adapt themselves, or lay their works out for this class of business. The particular case cited is an important one, for if the British steel makers after the War will not take up this line it is bound to have a marked effect in determining the type of turbine to be employed in the future, especially for large units.

The ten important recommendations made by the Institution, through our President, to the Board of Trade Committee, are no doubt fresh in your memories. Each one of these recommendations vitally affects the interests of us all, and it is to be hoped that most of them, if not all, will be given early effect to.

I cannot pass on to my next topic without paying tribute to the pioneer work done by Mr. Elder in delivering his excellent discourses throughout the country during the past year, and also to the work of the Special Committee of the Manchester Engineers' Club, out of which has arisen the Council for the Organization of the British Engineering Industries, and with which movement the name of one of our members, Alderman Walker, is so prominently identified.

THE LINKING UP OF POWER STATIONS.

It will be remembered that at the final meeting of this Local Section last session, Mr. E. T. Williams' paper on the electricity supplies of this country was discussed. It seemed to be the general opinion of the members of this Section that the interconnecting of most of the existing stations should precede the building of a few large super-stations, from which bulk supplies would be furnished.

The linking-up suggestion was not a new one. Mr. Watson in his Address* as Chairman of this Section in 1909 dealt with the question pretty fully, and the conclusions he therein arrived at have been borne out by the most exhaustive inquiry since made. Several municipalities had already proved the great financial saving that could be effected by interconnecting, especially in the lowering of fuel costs and the reduction in the quantity of stand-by plant necessary under such schemes.

There is no doubt, however, that Mr. Williams' paper was responsible for—and he is therefore entitled to great credit—again bringing the subject prominently before our public supply engineers, and as a result there are several schemes now maturing in different parts of the country. Probably the circular sent out by the Board of Trade, intimating that it would look with favour upon any linking-up proposals, and practically advocating such schemes wherever commercially possible, has had a great deal to do with the progress which has been made, for without the Board's sanction they could not be carried out.

It should be remembered that the personal factor is a very important one in cases of this kind where negotia-

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* *Journal I.E.E.*, 1910, vol. 44, p. 100.

[illegible] prestige, and even of position, through the association of their undertakings with larger ones. The latter view is not really a sound one. Whilst the distribution of elec-[illegible]s in the hands of each existing undertaking, [illegible] remain scope for the services of an engineer-manager.

The advantages of any linking-up scheme are by no means confined to the larger undertakings. There must be a certain amount of give and take in the national interest.

The linking up of the supply undertakings in Lancashire and Cheshire was already under the consideration of the [illegible] before the Board of Trade circular was issued, [illegible] lit is due to the engineers responsible for the [illegible]ation of the scheme recently described in the electrical Press. It is to be hoped that the Government will assist to some extent in the raising of the capital necessary for the carrying out of the work, seeing that the estimated annual saving therefrom is approximately 30 per cent.

Two other Committees are also at work on this subject. The question of electricity supply, from a national and [illegible]ing point of view, is being considered by a special [illegible]ee of our Institution, and a joint committee of the Incorporated Municipal Electrical Association and the Incorporated Association of Electrical Power Companies is going into the more immediate questions of organization and linking up of existing undertakings, etc. The recommendations of these committees should be of inestimable value to the whole community, and to the electrical [illegible]

[illegible] pate the more economical production of electricity in the near future, and the removal of many of those restrictions which have hampered the industry in the past. This will result in the more extended use of electricity for all purposes, and consequently largely increased benefits to the nation, for undoubtedly one of the greatest factors in [illegible]ful future for the manufacturers of the [illegible]p supply of electricity. It is strange [illegible]l the present World War to bring [illegible]

THE SUMMER TIME ACT.

Since our last meeting the Summer Time Act has been [illegible]dentally, I might add, in record [illegible] Although as a result of its [illegible] has been [illegible] The general trend of opinion and [illegible]at will be submitted to the Govern-[illegible]mittee appointed to consider the matter, I believe [illegible]

[illegible] their tariffs considerably without the approval of their consumers.

The Act has been rather aptly described as "The Artificial Light Saving Act" by one of the engineers whose output has been rather badly affected from its operation.

In Manchester the Act has led to marked benefits to domestic users. An examination of four residential districts reveals a saving of some 15 per cent. On the other hand in certain industrial and shopping districts a similar examination reveals an increase of some 8 per cent. In the latter case the increases are due to war-work and revival of retail trading. Obviously the Act has offered far less opportunity for economy in districts comprising shops closing at an early hour, than in residential districts. Its general effect on the various localities is thereby governed by the character of the lighting demands in these localities.

So far as it has been possible to institute comparisons at the generating stations in Manchester it is estimated that the reduction in lighting output from the Stuart-street station for the period covered by the Act was equivalent to 1 per cent of the total output, while the consequent saving in coal was about 600 tons. At the other Manchester Corporation stations the reduction was approximately 1½ per cent of the output, with a saving in coal of about 400 tons.

Our friends, the gas engineers, have of course been very much more affected than we have by the working of the Summer Time Act.

SUPPLY OF ELECTRICITY FOR WAR PURPOSES.

The past year has been a strenuous period with all supply undertakings. The output from the various stations situated in all the large manufacturing centres of the country has increased by leaps and bounds. It is difficult to conceive what would have happened in these centres if these large supplies of electrical power had not been readily available for our manufacturing firms. Municipalities and companies alike may each take credit for having contributed in no small measure towards the "munitions output" which is all essential to a successful issue from the present War.

It has been stated on high authority that judged by the weekly wage bill the Manchester district has as great an output of war material (using the latter term in the broadest sense) as, if not a greater output than, any other district in the country, not excluding the Tyne or the Clyde. It is not surprising therefore that the several electrical undertakings in this district should be experiencing a period of unprecedented stress.

ELECTRO-CHEMICAL INDUSTRIES.

One direct outcome of the War is the evident desire of the Government to render this country less dependent on foreign countries for supplies of certain materials; and in no case is this more marked than in certain chemical productions. The establishment of electro-chemical plants [illegible]

[illegible]

hour supply during the winter months of the year, thus furnishing an ideal load for central stations. One such consumer whose demand will far exceed that of any other on the system, not excluding the entire tramway demand, has just been connected to the Manchester supply undertaking. This supply will be given by the Corporation without the latter having incurred any capital outlay on plant to supply the same, because over the peak of the winter load, namely, from 3.30 p.m. to 5.30 p.m., and at any other times of severe atmospheric conditions, the consumer has arranged to reduce his load to zero if required. Otherwise the demand will be continuous night and day.

There are several other large consumers on the system taking a restricted-hour supply as above, but the specific one mentioned is by far the largest. Such desirable consumers are of course rightly entitled to the lowest possible rate per kilowatt-hour.

I feel sure that many undertakings could with advantage cultivate the restricted-hour consumer more than they have done in the past, and whilst benefiting themselves by reason of the attainment of a high load factor, they would also be assisting in the establishment of a greater number of electro-chemical industries in the country.

I cannot help thinking that inasmuch as the Government are directly interested in many of these electro-chemical plants, the development of this class of load by central stations would eventually lead to a closer and probably more beneficial connection between the Government and electrical supply undertakings. In many directions that will doubtless occur to the minds of the members, this course promises great advantages.

FUEL.

Great difficulty has been experienced by both gas and electricity supply undertakings during the past year in obtaining their necessary supplies of fuel, even where it could be proved as in Manchester that practically the whole output was for war-work.

Very meagre assistance has been obtained from the Government. The Act for limiting prices at the pit has been of little real value to many, and we hear in many quarters of the colliery companies evading its provisions. There is no doubt that additional legislation is required to enable our electricity stations, which are vital to the carrying on of the War and to the nation's interests in peace times, to obtain coal in sufficient quantities for their needs and at reasonable prices.

The fuel that is procurable to-day is inferior to that obtained before the War from the same pits, because of the greater percentage of the dirt content. A large proportion of the total fuel now offered was until recent years unsaleable. During the late coal strike more than one large electricity undertaking was only enabled to keep running by burning fuel which had been thrown on the rubbish-tip in the preceding years. To burn such inferior fuel called for conditions different from those previously obtaining in most stations, but higher draught and modern grates suggest that frequently the lower grades of fuel can be used economically.

The present high prices for fuel have caused colliery managers to recognize more fully the very great waste that undoubtedly has taken place at many pits. As much as from 10 to 15 per cent of the total output from some mines has in the past been left in the mines as being too small to warrant raising to the surface. Government control should in future obviate this wastage of our great national asset.

The high prices now obtaining for all classes of fuel undoubtedly call for the more efficient management of our boiler-houses, where it is generally admitted more can be done to improve the economical working of a supply undertaking than in any other department. The man in charge of the working of a large boiler-house should be an engineer of exceptional ability and should be well paid. The salary of such a man is a very small fraction of the saving he will effect. To him should fall the duties of seeing that combustion is obtained as perfectly as circumstances will allow; also that correct gas, water, and steam temperatures are maintained.

The indispensability of the analytical chemist in electricity undertakings of any magnitude is not yet sufficiently recognized. Only by regular testing can one ensure getting fuel of anything approaching constant quality from most collieries, and the knowledge that such tests are made is usually sufficient to make contractors careful in sending supplies to works where this practice is followed. Nor should the chemist's efforts be confined to raw fuel tests. He should be responsible for the correct treatment of the feed water and for seeing that scale and corrosion in the boilers are prevented, and the like.

POWER STATIONS OF THE FUTURE.

The large station of the future will, I believe, have a proportion of boilers gas-fired, the proportion being based upon the load factor in such manner that the extra capital incurred by the installation of by-product recovery plants will be remunerative, and the by-products of the bulk of the fuel used recovered.

Gas firing is not, and cannot be, a means of direct saving of fuel. The two-stage process of conversion of "coal to gas and gas to steam" must necessarily involve heat inefficiencies exceeding those in the direct conversion of "coal to steam." Skilled analysis and extensive experience tend to show, however, that with improved forms of producers the aggregate value of by-products recoverable from coal by conversion to gas equal or exceed the original coal value, and when extra capital and labour charges are taken into account, the procedure leads to a substantial rebate on fuel costs.

There were isolated cases on record in the days when slack could be bought at 6s. or 7s. per ton, where large boiler installations were fired throughout the year substantially for nothing, and as the value of the various by-products fluctuates largely in sympathy with coal values, one might expect a net saving by the system of between 4s. and 7s. per ton of coal consumed.

As to the exact method which will survive, one hesitates to express an opinion. There are broadly speaking two fundamental types of gas recovery plants :—

(*a*) *Low-temperature distillation.*—In which coal is converted to coke or smokeless fuel yielding gas, spirits such as benzol, toluol, and the like, heavier oils, tar, and a comparatively small amount of sulphate of ammonia.

(*b*) *Producer.*—In which coal is burned to ash with yield of abundant gas, a comparatively poor tar, the residual value of which about pays the cost of collecting, but high yield of sulphate of ammonia.

A [illegible] of the two [illegible] but [illegible] relative value of [illegible].

[illegible] that practically every trial has been conducted with Lancashire or [illegible]. These [illegible] and admirably designed around fire grates for high [illegible] ect firing, are far from ideal for gas [illegible] possible with a certain type of boiler. Figures such as these cannot, however, be anticipated in practice on a large scale. There is, however, a fine field open for the invention of the large and highly efficient [illegible] The [illegible] Nicholson might be pursued in this connection.

Obvious advantages incidental to gas firing will be the [illegible] r grades of coal, and clean, comfortably [illegible] ess boiler-houses, involving low maintenance charges.

More than usual interest attaches to this subject by reason of the published experiments on a sufficiently large scale that are to be made at the Yorkshire Power Company's station at Barugh, near Barnsley, and at the Southwick power station of the Brighton Corporation. In each case the electricity undertaking is to purchase gas in [illegible] n process.

It will therefore be seen that the financial risks, such as they may be, are carried by the company supplying the gas. Provided the guarantees of the latter are fulfilled it would appear from the particulars published that the Brighton Corporation has made an exceptionally good bargain. In any case the results will furnish an interesting comparison with what can reasonably be achieved with a scheme working on producer lines.

Apart from the question of gas-firing versus coal-firing, considerable attention of late has been given to the design of new boiler-houses and the utilization of larger units. In this connection there is a marked contrast between British and American practice.

Much could be said on both sides, but inasmuch as the [illegible] elled a revision of our ideas generally, on the [illegible] f generating units to be employed, it seems not improbable to expect that British engineers will aim at increasing the size of individual boiler units in the [illegible] decreasing the number to be installed. It [illegible] er, a moot point whether American engineers have not gone too far in the direction of the size of unit [illegible] of American boiler plant is by no means established. A compromise between the two somewhat conflicting views would appear to be the correct line on [illegible] this country. The proposed use of large gas-engine-driven generators is now clearly a thing of the past. Their manufacture was never taken up very seriously by many engineers in this country.

Turbine plants undoubtedly hold the field, and in the near future one may confidently anticipate seeing units of 20,000–25,000 kw. being installed in some of our large British stations. The design of plant of this size is in a most interesting stage, and the comparative data that will be obtained from alternative types, both as regards capital costs and the operating results, will be studied with the greatest interest by all associated with power supply undertakings.

Rate Relief

The War has served to bring into prominence again the vexed question of rate relief from the trading departments of municipalities.

In these days of a 5s. income tax, and with the possibility of an increase even on this figure, surely the time has come for a drastic revision of the methods followed by many municipalities of exacting large sums of money by way of rate relief from the trading departments. Whilst it may well be argued that the claim of ratepayers to receive something out of trading profits is irresistible, so staunch a supporter in the past of the principle of rate aid as the *Accountant* in a recent issue wrote as follows:—

> "Our own view is that ratepayers are entitled to be remunerated for their financial guarantee; but we would put such remuneration on a basis of a sum not exceeding ½ per cent upon the outstanding loans for the time being. We think that any municipality applying profits in excess of that amount towards the relief of rates is abusing its position."

This extract is, I submit, significant of the change in public opinion. Most engineers are agreed that the nearer electricity supplies are furnished to cost price the better for the community at large.

As an alternative to a system of rate relief that may be laid down by any municipality (and which runs counter to the above proposition regarding cheap supplies) it would not be unreasonable for the ratepayers at large—who would receive no direct benefit under a no-rate relief scheme—to stipulate that the supply undertaking should, in addition to providing for debt redemption, at the same time make some provision over an extended period of years for a renewal of the assets of the undertaking when worn out, so as to avoid recourse to borrowing. To place a figure on this "extended period of years" is a question that requires very close consideration, as obviously it would not be fair to burden present consumers for the benefit of posterity.

SCOTTISH LOCAL SECTION: CHAIRMAN'S ADDRESS,

By J. K. STOTHERT, Member.

(Address delivered at Glasgow 14 November, 1916.)

During recent times inventive minds have no doubt found less opportunities to create novelties, than they have for the application of existing inventions in all branches of electrical and mechanical science to the present needs of the War. Those outside the immediate conduct of the War know little of the application of science to military inventions, but from what they glean of the improvements in guns, and of the means of destroying hostile submarines and airships—not to speak of the "tanks"—they realize that the imagination and inventiveness of military engineers have been strenuously at work.

What we, as electrical and mechanical engineers, do realize more fully, however, is the talent for organization that has shown itself to have been latent in our race, and that has come fully to the front recently in the extraordinarily quick construction of explosive and shell factories. Many of these have sprung up like mushrooms, rivalling all the tales that we hear of the aptitude of our American friends for celerity, and equalling even, as far as one can gather, the rapidity with which they have themselves given us ever-increasing supplies of munitions.

In the case of a large majority of these factories, their rapid construction and setting to work would not have been possible had it not been for central power and lighting stations being available; and too much credit cannot be given to the great results that central station engineers have achieved in meeting the requirements of these factories, both with their existing plant and their extensions.

Happily, movements are on foot to recognize this on a larger scale than hitherto, and it is hoped that in the future, when peace reigns again and normal conditions prevail, electric power installations will be brought into the service of the people of the country without going through the vicissitudes in capitalization that characterized this development in the past.

As far as the technical developments of means of producing electricity are concerned, these have been more in detail than fundamental, but the obvious necessity of economizing fuel is leading to refinements in the steam-utilization plant. Experiments are about to be made with stage re-heating in steam turbines—a subject with which many members are already to some extent acquainted, and with which the honoured name of Ferranti is associated.

The refinements in steam generating have not only been achieved by increasing the efficiency of the boilers and mechanical stokers, but the steam generated has been efficiently used, as it has become practicable to increase its temperature by superheating. Improvements in the application of liquid and gaseous fuel are also under consideration.

Improvements in the steam-generating plant are coming more into use, in the direction of reducing the expenditure for labour per generating unit. This is mainly achieved by mechanical firing and large steam-generating sets, and by mechanical appliances for conveying the coal from railway truck or ship right into the furnace without manual labour, and conveying the ashes to the dump, mechanically or pneumatically. Economies of space and cost of building are incidental to this development.

Though this Address is affected by the War, a topic that pervades us night and day, I do not think it would be complete, or that I should be justified in dealing as cursorily with the technical aspects of our profession, if I were not to touch upon the "after-War" problems that will present themselves to us and call for greater and improved efforts on the part of employer and employed and the services of the electrical engineer to at least the same, if not a greater, extent than of engineers specializing in any other department of engineering.

The first thing that naturally occurs to one's mind on hearing the words "Trade after the War" is the protection of our industries from competition with enemy and neutral nations; but this is not going to the root of the matter, and perhaps I shall have something to say about this later. The suggestion, however, at least shows that one cannot approach the subject without appealing to what was at one time a political controversy, and political subjects at this war time we are supposed to avoid. I should, however, like now to assert, what has been stated by Canadian statesmen when visiting this city, that this subject of so-called Tariff Reform, or Trade Protection, should not be made a political football for the sake of catching votes, but should be treated, as it will be treated, in all seriousness, as free, we hope, from political bias as the Army or the Navy.

Has it not occurred to members that what is happening now in this dreadful World War, is what has been advocated by the anarchist? That is to say, the destruction of all existing society and forms of government for the purpose of re-building and re-establishing a fair and a newer system of society in general. No one can deny that this war is sweeping away old ideas, old prejudices, and that our pre-war conceptions of things that are right and things that are wrong will be, and are being, fundamentally altered. The old happy-go-lucky days of arm-chair ease and trusting that things generally will come right somehow, the old days of indifference and apathy are gone for ever.

If we are to emerge from this War and taste the fruits of victory, it will be generally agreed that the first thing to which we have to apply our minds in making this new Britain, that is to rise like a phœnix from the ashes of the old, is the subject of education. It is not my province to-night to teach those who have studied this subject very [illegible] herding large numbers of children into a class-room under [illegible] Whitehall, is not the best way to get the best results out of the future citizens of the Empire. It would be better to revert to some extent to the old dominie system, which drew out and unfolded the capabilities and capacities of the pupil. Neither will the system of the English public schools and their like, spending so much time in acquiring [illegible] reduced. In the higher grade and public schools of England the methods will have to be more intensive and the State will have to take a hand in the care and education of what, owing to the heavy casualties that the nation has suffered and will yet have to suffer, is the precious material of children between the ages of 14 and, say, 17.

What interests us all most with regard to education, as an engineering society, is, however, perhaps the question of technical education and apprenticeship. Much has been written on it, and there is hardly any subject which has been more discussed. Curiously enough, at one time the trade union societies endeavoured to limit the number of apprentices which a firm could bind, in proportion to the number of journeymen employed. This was part and parcel of the general scheme before the War, which they had in mind, that the restriction of output meant additional wealth in the form of wages to them. The employer, on the other hand, wanted to employ as many apprentices as suited him, and allowed these youths to come into his works and acquire as much knowledge and practice of the particular trade, to which they were bound, as their capabilities and industry would permit. The old-time apprentice, I need hardly say, was bound to a master, and the master in return for services had certain direct duties to perform, all specified in the apprenticeship bond. But the old master did take a pride in his apprentice and did teach him all he knew, and we read and hear of some cases where the apprentice exceeded in skill his master. Many members may have seen the apprentice pillar in Rosslyn Chapel as an instance of this. It is easy to glean from these remarks what I am [illegible] the number of apprentices, the masters, as a rule, do not give sufficient attention to the education and technical training of the apprentices under their care. This must be improved. The results of the War will see to that; for, not taking into account the effect which the dilution of labour is bound to have, on the old methods of training [illegible] the trade unions will see, with so many [illegible] their ranks to fill up that the restriction of [illegible] the masters must see that a little more care with and a little [illegible]

[illegible]

—responsible only to the works manager—whose sole duty it is to teach the apprentices and bring them on, and it has been found that this is very beneficial, not only to the apprentices but also to the employers. They have tried many other things with regard to apprentices. They have erected a restaurant and provided facilities for cheap and wholesome food, recognizing that young and growing youths, working hard and long hours, require perhaps better sustenance than they would otherwise get. They have also thought out a system whereby the better educated and brighter boys can get a technical education as part of their apprenticeship system, and as part of their duties to the apprentice. They have tried that system, but with regard to the latter part of it I am sorry to say that up to the present the success has not been altogether what they expected, owing to the want of receptivity and sympathy on the part of the lads, and other causes, but they are sure that they are on the right lines, and that in the end they will succeed.

It is possible that technical training throughout the country, and the apprentice system, will have to be taken in charge by a central authority. People may say that this must be done by the Government and that the Government must act at once and act quickly, and they are right. Well, the Government will not act, and it will not act quickly, *unless* we can go to them and take in our hands a mandate from their masters. Our Constitution and our political system is such that we cannot think out any of these reforms and any of these new systems without coming back and being faced at every turn by this elementary political principle.

With regard to technical education, when and how is it to be applied? Are the youths to work from half-past six o'clock till half-past five, and then go to their evening schools, jaded, tired and weary? Are these youths to work in pairs and thus be allowed so many days a week to work in the shop and the remainder of the time to work at the college? Are they to work so many years at the bench and so many years at college? Are they to work in the summer at the bench and in the winter at the college? These are all systems which have been tried, and which have been advocated, and what I would say is that for some classes of apprentices one system is the better, and for another class another is the better. Possibly, for the more highly educated, the shops in the summer and the university in the winter will give good results. A system of a 4 or 5 years' apprenticeship—the first year at the technical college, the next year with an affiliated company, the third year again at college, and the fourth and fifth years in the shops, has worked exceedingly well. But these are all subjects which must be dealt with, and can only be dealt with, like every other subject in connection with trade after the War, by conferences and alliances between masters and men, sectionalized into their various trades and divisions.

The subject of technical education naturally leads one on to the subject of research and experiment. We have seen in this country the difficulties that the Allies got into when they were wanting in co-ordination, which enabled our enemy to shuttlecock his armies from one front to another. When we were able to organize and co-ordinate all our forces and to act with one mind, a different state of [illegible] the fighting on the Continent will be true in our Trade Fight after the War. No longer must each firm fight entirely for itself. No longer must they keep their own experiments and researches secret for their own individual benefits. There must be a freer interchange of views, a freer disclosure of results, or associations in the various trades so that their researches can be combined and the results of this research mutual. In fact, any business which refuses to act in this co-operative way will be avoiding a public duty, with possibly dangerous results to its continued existence. Here, indeed, is a duty then for learned societies to help more than ever they have done in the past with research work, to do something practical and useful, rather than shrivelling up into societies, debating only those subjects which practical firms do not desire to keep to themselves. I am thankful to say that our Institution is fully alive to this. It has a Research Committee of its own. It is working in conjunction with the Committee of the Privy Council and other bodies, and I take it that what we are doing is being done by others.

We now come to the question of population and labour. It has been said, but not well said, that all wealth is the result of labour. It would be truer to say that all wealth is the result of well-directed labour, which means labour and brains, which is another way of saying that the wealth of a nation depends upon its power of production and its ability to produce. With large numbers of men killed or disabled, our power of production will be lessened when the War is finished, and we shall need all the brains and labour—skilled, semi-skilled or unskilled—that is then available. We must recuperate, and recuperate quickly, if we are to keep our place in the world, and if we are to compete with neutral nations which have been progressing while we fight, and whose populations have not been diminished in the way they will be with the belligerent nations. How are we going to get over that? We must do it by uprooting from the minds of the workers that fallacious theory that the restriction of output increased the wealth of the nation by creating a scarcity in commodities, and therefore restricting the markets. We must do it by using our brains and inventive faculties for every possible labour-saving appliance which will tend to cheapen manufacture. We must do it by everyone waking up to the fact that we must quarrel no more amongst ourselves, and that capital and labour must work hand in hand. There must be no more avaricious employers. We must have no idle or unreasonable workmen. How is all this to be done? How is a better understanding between employer and employed to be arrived at? How are strikes and lock-outs to be prevented? These are problems which no one man can solve, but these are problems about which we must all think; and as every little tells, so every individual effort to attain these objects will be something done to build up the bulwarks of our Empire and to show our enemies that in trade matters, as we have shown them in military matters, we are not indeed a decadent nation.

Some people may think, especially those who have had control of a large number of workmen, that the problem of a better understanding between employers and employed is almost insoluble; but when both sides are working with singleness of aim to attain the same result, it is astonishing how matters can adjust themselves and how difficulties previously conceived to be insuperable melt away. As an instance of this, we have the result of the meeting of over 3,000 representatives of the mining industry held in London last month unanimously adopting a resolution pledging itself to do everything in its power, by co-operation between employers and workmen, to secure an increase in the output of coal.

I referred at the beginning of my remarks to the question of protection of our industries from competition with enemy and neutral nations. This is a question which concerns not only ourselves, and when I say ourselves I mean our colonies and dependencies, and those other nations which form part of the British Empire, as well as our Allies in the present War. The Paris Conference, we understand, dealt with this matter and we could not at the present time lay down any hard and fast rules or ideas as to how this matter should be treated. Some Professors of Economics still think that Free Trade as practised before the War should be adhered to, and they still use the same argument that putting up a protective wall would re-act on the consumers at home. But I think we may take it that the general opinion of the country, and certainly the opinion of the home of Free Trade—at least if we can judge by the action of the Manchester Chamber of Commerce—is that something should be done by which new industries may spring up to employ our population in the manufacture of articles which might as well be made in this country, with our own labour, as be made in Germany, because in the past we have been too apathetic to exploit and carry on some of those industries, the process of which our own people were the first to invent.

We knew in pre-War times what relentless competitors the Germans were. We have every reason to assume that after the War they are bound to attempt to build up their credit by still greater efforts, and while we can prevent, if thought necessary, our own country from being their happy hunting-ground in the future, we cannot preclude them from competing with us in neutral countries, or any countries in which the question of cost is considered along with the question of nationality. It is not only energy in the ordinary sense of the term, produced by the will to achieve, that will accomplish this, but the will to achieve must be associated with the will to acquire, and the Government must put our labour conditions, our trade conditions, and our capital conditions, on such an improved footing that other countries can say of Great Britain that they are the most enterprising in meeting the needs of those countries, the most scientific in their designs, the most apt in carrying out a transaction, and the most honest in their workmanship and materials.

This brings us back again to the question of education and languages. We must protect ourselves in this respect; business men trading in foreign markets should either themselves or through their agents have a knowledge of the languages of the countries in which we wish to establish ourselves so firmly that the Germans cannot oust us. What is more important to us almost than a thorough knowledge of the languages is the study of the national characteristics and business customs of those countries. To take one instance at the present time, a great deal of thought and some organization is taking place with regard to trade with Russia. Chambers of Commerce, universities and corporations are on the point of establishing [illegible] interchange of commercial information. Naturally Russia, when the War is finished, cannot be so friendly with that nation who had, at all events regarding machinery, a great control of their business. I do not think I should be [illegible] we must go ahead in order, as I have said, to protect [illegible] refers to Russia refers to every other allied or neutral [illegible]

[illegible] competition with neutral countries and other products not only in our own markets, but again in the markets of [illegible] to outstrip us in the race? Is it true, as some say, that America in the electrical industry has outstripped Great Britain? When we have such names as Faraday, Swan, Kelvin, why should the electrical industry take second place, if it has? Yet possibly, for the want of research, for the want in the past of Government support, our industry, which has indeed made such wonderful progress even during the lifetime of younger men than myself, has been outstripped by Germany and America. The incandescent lamp industry is an instance. I cannot tell from personal experience if American practice in power work has outstripped the power work of this country, but I do know that American firms have been more enterprising by establishing British companies than our own pioneers and capita- [illegible] countries has been the result of Government legislation. Who does not remember the Electric Lighting Acts of the eighties? What difficulties have been created in high-tension transmission by the Post Office and Board of Trade rules? Then take the question of electric traction. This, during the last few years, has been going ahead. We have [illegible] llent system of electric trams, but we, [illegible] re, haven't a single electric [illegible] trict. I believe the same [illegible] that unless we can show foreign buyers work of this sort [illegible] rs will go to those [illegible] countries who can and do cater for their [illegible]

[illegible] purposes, but unless the Government proceed on more [illegible] to do, no [illegible]

of the Board of Trade, which collects for us and for the [illegible] and river steamers, examines and tests our marine boilers, but takes no interest [illegible] issues provisional orders and regulations that very often prove obstructive. In trade it is not really helpful. It gives us no information of new business, and therefore a new [illegible] Connected with the new Ministry of Commerce, which so [illegible] be a new consular system, more active, more informative, and with more power. Our present consular system is bound up with the old demon of red tape. I know from agents in foreign countries that the routine necessary to get information from the Foreign Office sometimes takes at least two years, while foreigners could get the same information which would enable them to obtain the order against ourselves in two days. That is what we have been up against and what we shall be up against, and therefore it is obviously necessary that one of the bricks of our new fabric must be a redeemed and re-organized consular service.

Many reasons have been put before the Government, and they have received many deputations with regard to the Ministry of Commerce. The associated Chambers of Commerce, you will remember, sent a deputation to interview Mr. Asquith, and perhaps will also remember how the Prime Minister received that deputation: how he said, when it was pointed out to him that a Government should at least have one Department of business men to guide a business nation, that he, as a lawyer, had spent most of his life in getting business men out of difficult situations into which they had got themselves. I believe he called these difficult situations "holes." I bring this incident to members' attention in order to remind them that in this, as in other matters I have indicated, we can expect no help from the Government unless our requests are accompanied by a strong popular demand.

This Ministry of Commerce would, we see, poach on the preserves of the Board of Trade and the Foreign Office, but it would, I hope, be even more far reaching than this, for I should like it to take in hand the housing of the workers, and thus encroach upon the duties of the Local Government Board, or at all events work hand in hand with this department.

For I am convinced that the root of much of the industrial unrest and discontent is planted in the fertile soil of bad housing and miserable environment. I have no fear [illegible] who will, in conjunction with the Government and local authorities, look after the housing of their workpeople, will [illegible]

[illegible] will tend to lift but an individual out of his own groove and cause him to think what is to be the fate of our nation, and what *he* can do towards the rebuilding of our Empire and [illegible]

PROCEEDINGS OF THE INSTITUTION.

591st ORDINARY MEETING, 9 NOVEMBER, 1916.

Mr. C. P. **Sparks**, President, took the chair at 8 p.m.

The minutes of the Annual General Meeting held on the 11th May, 1916, were taken as read, and were confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : A. H. Bate, S. E. Britton, The Diesel Engine Users' Association, M. Farrer, Messrs. W. T. Henley's Telegraph Works Co., Ltd., H. V. Henniker, W. Judd, E. de M. Malan, Professor T. Mather, F.R.S., F. H. Nicholson, E. Parry, The Public Trustee for the late Mr. E. Donovan, S. Sharp, J. L. Smith, R. T. Smith, J. K. Stothert, W. W. Thomas, and The "25 Club."

Building Fund : J. S. Highfield.

Library : Colonel W. F. Badgley, C. J. Beaver, The Bennett College, The Board of Education, J. O. Boving, The Canadian Ministry of Trade and Commerce, W. C. Clinton, W. Corin, The Director General of Electric Exploitations (Japanese Department of Communications), The Electrical Society (New York), The Engineering Standards Committee, A. P. M. Fleming, Dr. C. C. Garrard, Sir Robert Hadfield, F.R.S., H.M. Inspector of Factories, The Institute of Radio Engineers, W. H. N. James, The Japanese Imperial Department of Communications (Electrotechnical Laboratory), Dr. G. Kapp, C. H. Merz, Office National des Universités et Écoles Françaises, C. Polychronis, L. G. Radcliffe, F. C. Raphael, Messrs. Rentell & Co., Ltd., The United States Bureau of Standards, The United States Department of Agriculture, W. L. Upson, L. H. Walter, and W. Wilson.

Museum : H. B. Bompas, J. O. Girdlestone, The Liverpool Corporation, and J. H. Rider.

The President announced that the Council had elected Professor G. Carey Foster, LL.D., D.Sc., F.R.S., to be an Honorary Member of the Institution.

The Premiums referred to in the Annual Report of the Council for the year 1915–16* were then presented by the President.

The **President** : The Council have awarded Dr. S. Z. de Ferranti the Willans Gold Medal and Vellum Certificate for his Inaugural Address as President on the 6th November, 1910. The Willans Premium is awarded alternately every three years by the Institution of Mechanical Engineers and by our Institution, that is to say, every six years our Institution awards the Premium to the author of what the Council considers to be the best paper read since the previous award. It is with the very greatest pleasure that I present my old friend Dr. Ferranti with this Premium. Although delivered six years ago, his Address is as well worth reading to-day as it was on the day it was written. We are still trying to work on the lines laid down in that Address, and I am sure it will always be regarded by the Institution as one of the most epoch-making papers we have had.

Dr. Alexander Russell, Vice-President, then delivered the Eighth Kelvin Lecture, entitled "Some Aspects of Lord Kelvin's Life and Work" (see page 1).

A vote of thanks to the Lecturer was proposed by the President and seconded by Dr. S. Z. de Ferranti, and was carried with acclamation.

The meeting adjourned at 9.15 p.m.

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* *Journal I.E.E.*, 1916, vol. 54, p. 553.

592nd ORDINARY MEETING, 23 NOVEMBER, 1916.

Mr. C. H. **Wordingham**, Vice-President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on the 9th November, 1916, were taken as read, and were confirmed.

The Chairman announced that the Council had elected Sir William Slingo to be an Ordinary Member of Council in place of Captain R. J. Wallis-Jones, who had resigned on account of pressure of his military duties.

Messrs. A. E. A. Ridgway and T. P. Shilston were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Member.

Hutchison, Donald Maxwell W.

Associate Members.

Baker, John Austin, Lieut., A.S.C.
[illegible], Frederick Rowland.
Battle, George Richard.
Boyton, Robert Alexander S.
[illegible], Frederick Harry.
[illegible], Percival, Capt., R.E.
Clegg, Fred.
Corbett, Robert William T., 2nd Lieut., R.E. (T.).
Fraenkel, Poul Hermann.
Fraser, Alexander.
Fraser, William.
Frere, Edouard.
Grapes, Herbert John.
Hopton, John Henry.
Packer, John Lewis.
Pallott, Charles Frederick.
Redclift, Stanley Whitlock.
Rorke, Alexander, Lieut., R.E.
Sloan, Alastair Drew.
Smith, John Ralfe.
Thomas, Thomas Rees.

Graduates.

Basu, Bhupendra Nath.
Bowey, Norman.
Brodsky, Vladimir.
Chang, Si Yung.
de Oliveira, Antonio Carlos.
Iyer, Seshagiri Subramania.
Lane, Eugenio Salles.

Students.

Aldunate, Alfredo.
Ballard, Clarence Mansfield, 2nd Lieut., R.E.
Bennett, Owen Hewett D.
Binnie, Richard Douglas.
Buist, David Maxwell.
Burgum, William Thomas.
Church, Leonard Phillips.
Clegg, Percy.
Cowen, John Sydney Maurice.
Entwistle, Gertrude Lilian M.
Gibson, Henry Joseph.
Gordon-Campbell, William Francis.
Grace, Arthur William.
Gresty, George.
Hopwood, Edward Ernest.
Hoseason, Donald Bright.
Ives, Charles Laurence.
Moffat, James.
Osborne, Ralph.
Perry, John Francis.
Radley, William Gordon.
Reily, Percy Arthur.
Riley, Thomas Sharp.
Rogers, Arthur Harry E.

Students—continued.

Storey, Charles Ernest.
Tapsell, Herbert James.
Thomas, William John.
Thornton, Cecil V.
Wheatley, Edwin Kenneth.
Wilkinson, Harold Claud.
Wilson, Stuart Keith.
Wust, Alexandre.

TRANSFERS.

Associate Member to Member.

Digby, William Pollard.
Gardiner, Bernard Calwoodley, Major, R.M.L.I.
Launchbury, Frederick James.
Matthewman, Thomas Henry.
White, Bruce Gordon.

Associate to Associate Member.

Shepheard, Hubert Beaumont.

Graduate to Associate Member.

Danson, John Rhys.
Golden, Randal Eugene.
Gomes, Jose Vaz Monteiro.
Grice, Percival.
Hilder, Walter Trevethan.
Monson, Lewis Oswald.
Wilkinson, Frederick Randolph.

Graduate to Associate.

Barr, Thomas Hall.

Student to Associate Member.

Abbott, John Russell.
Algar, Horace.
Anderson, Sydney Drummond, Lieut., R.E. (T.).
Ashworth, Edgar Philip.
Boa, Frederick Crossley.
Fruhe-Sutcliffe, Reginald.
Gwyther, Henry James.
Hill, Laurence Davenport.
Hughes, Philip Robert, Lieut., R.F.A.
James, Reginald Northcott.
Lisle, Arthur, B.Sc.
Martin, Ralph Otway.
Phelps, Henry Dampier.
Philipp, Richard Charles.
Ryley, Walter.

Student to Graduate.

Martins, Almir Machado.
Smith, Maxwell.
Wilkin, David.
Willcock, Arthur.
Williams, Thomas Davies.

A paper by Mr. J. S. Peck, Member, entitled "The Parallel Operation of Electric Power Stations" (see page 61), was read and discussed, and the meeting adjourned at 9.50 p.m.

INSTITUTION NOTES.

ELECTION OF AN HONORARY MEMBER.

The Council have elected Professor G. Carey Foster, LL.D., D.Sc., F.R.S., Past President, to be an Honorary Member of the Institution.

NEW MEMBER OF COUNCIL.

The Council have elected Sir William Slingo to be an Ordinary Member of Council to fill the vacancy caused by the resignation of Captain R. J. Wallis-Jones.

REPRESENTATIVES OF THE INSTITUTION ON OTHER BODIES.

The following is a list of representatives of the Institution on other Bodies, and the dates on which they were appointed :—

Body	*Representative*	*Date of appointment*
British National Committee of the International Illumination Committee	Mr. F. Bailey Mr. W. Duddell Mr. K. Edgcumbe Mr. H. T. Harrison Prof. J. T. Morris	27 Nov., 1913 ,, ,, ,, ,,
Conjoint Board of Scientific Societies	Sir John Snell Mr. C. P. Sparks	29 June, 1916 ,,
Corrosion Committee of the Institute of Metals	Mr. J. Christie	13 Jan., 1916
Engineering Committee of the Advisory Council for Scientific and Industrial Research	Mr. J. S. Highfield	9 March, 1916
Engineering Standards Main Committee	Col. R. E. Crompton Sir John Snell Mr. C. P. Sparks	2 April, 1914 ,, ,,
General Board of the National Physical Laboratory	Mr. R. T. Smith Sir John Snell	26 Nov., 1914 21 May, 1914
Governing Body of the Imperial College of Science and Technology	Mr. W. Duddell	21 May, 1914
Governing Body of the School of Metalliferous Mining (Cornwall)	Mr. C. P. Sparks	23 Jan., 1913
Munitions Inventions Department (. . . . . Panel)	Sir John Snell	12 Oct., 1916
National Conference of Representatives of Gas and Electricity Undertakings	Mr. J. S. Highfield Mr. C. P. Sparks	29 April, 1915 ,,
Sectional Electrical Committee of the Engineering Standards Committee	Mr. W. Duddell Mr. F. Gill Mr. J. S. Highfield Mr. R. T. Smith Mr. C. H. Wordingham	21 May, 1914 ,, ,, ,, 18 Nov., 1915

INCOME TAX.

The following reply has been received by the Institution of Civil Engineers to a letter (26 June, 1916), on behalf of various professional Societies (including the Institution of Electrical Engineers), drawing the attention of the Chancellor of the Exchequer to the position of many professional men as regards income tax under present conditions :—

TREASURY CHAMBERS,
WHITEHALL, S.W.
17 *July*, 1916.

DEAR SIR,

In reply to your letter of the 26th June with reference to the position of professional men as regards Income Tax, I am desired by the Chancellor of the Exchequer to say that in the Finance Bill now before Parliament it is proposed to apply to the year 1916–17 the relief originally conferred by Section 13 (I) of the Finance Act, 1914, Session 2.

It is further proposed that where an individual's actual income from all sources for the year 1916–17 falls more than 10 per cent below the income as assessed or charged, this diminution of income shall, as in 1915–16, entitle him to claim a special relief. For 1916–17, however, in the case of such individuals the relief is to take another form, viz. the repayment of the difference between the amount of tax actually paid or borne for the year, and the amount that would be paid or borne on the simple basis of the actual year's income.

I am, etc.,
(Signed) H. P. HAMILTON.

J. H. T. TUDSBERY, Esq.,
Secretary, The Institution of Civil Engineers.

EMPLOYMENT OF DISABLED SAILORS AND SOLDIERS.

Last summer the Council of the Institution, in cooperation with the Education Department of the London County Council, appointed a Joint Committee to make arrangements for classes at the Northampton Polytechnic Institute, Clerkenwell, E.C., for giving a preliminary training to disabled sailors and soldiers

[illegible]

The courses are free to the men and the work consists of demonstrations and exercises in the first principles of [illegible] stations and generating stations in the London district and instruction is given by the men in actual charge of the stations.

A third group of 20 men have just completed their course, and engineers having vacancies which could be offered to them are requested to communicate with Dr. Walmsley, Principal of the Northampton Polytechnic Institute, Clerkenwell, London, E.C., who will also be [illegible] to send full particulars and application forms for [illegible] to the courses to disabled sailors or soldiers wishing to join.

The question of extending the scheme to other towns is under consideration.

[illegible]

Among the Committees appointed by the Council for [illegible]

(The President is an *ex-officio* member of all Committees.)

Electricity Supply Committee.

Mr. R. A. Chattock.	Mr. S. L. Pearce.
Mr. C. H. Merz.	Mr. T. Roles.
Mr. G. W. Partridge.	Mr. W. B. Woodhouse.

([illegible] best means of co-ordinating and improving Electricity Supply in the United Kingdom.")

[illegible]

Mr. W. Duddell, F.R.S.	Mr. J. E. Kingsbury.
[illegible]	[illegible]

Mr. G. S. Ram.

[illegible]

Mr. A. S. Barnes.	Prof. E. W. Marchant.
[illegible]	Prof. T. Mather, F.R.S.
Mr. H. W. Clothier.	Mr. C. H. Merz.
[illegible]	Mr. W. M. Mordey.
Mr. W. Duddell, F.R.S.	Mr. G. H. Nisbett.
[illegible]	[illegible]
Dr. R. T. Glazebrook, F.R.S	Dr. A. Russell.
[illegible]	Mr. J. Swinburne, F.R.S.
Mr. H. H. Harrison.	[illegible]
[illegible]	Mr. W. B. Woodhouse.
[illegible]	Mr. C. H. Wordingham.

[illegible]

[illegible]	[illegible]
[illegible]	Mr. S. W. Melsom.
[illegible]	Mr. R. B. Mitchell.
[illegible]	Mr. H. F. Proctor.
Dr. R. T. Glazebrook, F.R.S.	Mr. C. H. Smyth.

[illegible]

[illegible]

Mr. A. S. Barnes.	Dr. R. T. Glazebrook, F.R.S.
Mr. W. Duddell, F.R.S.	Dr. A. Russell.

[illegible]

[illegible]

Mr. W. Duddell, F.R.S.	Mr. C. H. Merz.
Dr. R. T. Glazebrook, F.R.S.	Dr. A. Russell.

Mr. C. H. Wordingham

[illegible] Panel.	*[illegible]*
Mr. A. P. M. Fleming.	Mr. J. Allan.
Dr. R. T. Glazebrook, F.R.S.	Mr. A. R. Everest.
Mr. G. S. Ram.	Mr. A. P. M. Fleming.
Mr. G. Schultz.	Dr. R. T. Glazebrook, F.R.S.
Mr. J. M. Wallace.	Mr. C. H. Merz.
Mr. J. F. Watson.	[illegible]
Prof. E. Wilson.	Mr. J. F. Watson.
Mr. C. H. Wordingham.	Mr. C. H. Wordingham.

Ebonite and Mica Research Panel.	*Porcelain Research Panel.*
Mr. J. Allan.	Mr. W. Duddell, F.R.S.
Mr. J. H. C. Brooking.	Mr. A. P. M. Fleming.
Mr. W. Duddell, F.R.S.	Dr. R. T. Glazebrook, F.R.S.
Mr. A. P. M. Fleming.	Mr. J. W. Harris.
Dr. R. T. Glazebrook, F.R.S.	Mr. J. L. Langton.
Mr. F. L. Henley.	Dr. J. W. Mellor.
Dr. A. Russell.	Mr. C. H. Merz.
Mr. G. Schultz.	Dr. A. Russell.
Mr. J. F. Watson.	Mr. T. Taylor.
Mr. C. F. Wilkins.	Mr. J. H. Tucker.
Prof. E. Wilson.	Mr. J. M. Wallace.
Mr. C. H. Wordingham.	Mr. J. F. Watson.
	Prof. E. Wilson.
	Mr. C. H. Wordingham.

Insulating Oils Research Sub-Committee.

Mr. A. S. Barnes.	Mr. J. L. Langton.
Mr. W. P. Digby.	Dr. A. C. Michie.
Mr. W. Duddell, F.R.S.	Mr. W. B. Parker.
Mr. A. R. Everest.	Mr. L. G. Radcliffe.
Mr. A. P. M. Fleming.	Mr. C. Rodgers.
Dr. R. T. Glazebrook, F.R.S.	Mr. J. Roothaan.

Mr. T. C. Thomsen.

Magnet Steels Research Sub-Committee.

Mr. W. Duddell, F.R.S.	Sir R. A. Hadfield, F.R.S.
Dr. R. T. Glazebrook, F.R.S.	Prof. T. Mather, F.R.S.

[illegible]

Mr. J. O. Callender.	Dr. R. T. Glazebrook, F.R.S.
Mr. W. Duddell, F.R.S.	Mr. C. Vernier.

Mr. C. H. Wordingham.

[illegible]

Mr. W. Duddell, F.R.S.	Mr. W. M. Mordey.
Mr. J. E. Kingsbury.	Dr. A. Russell.
Prof. O. W. Richardson, F.R.S. }	Appointed by the Physical
Mr. F. E. Smith }	Society of London.

SECTIONAL COMMITTEES:

Electric Traction.

Mr. H. W. Firth.
Mr. F. Lydall.
Mr. C. H. Merz.
Mr. G. W. Partridge.
Mr. H. F. Proctor.
Mr. R. T. Smith.

Electricity in Mines.

Mr. A. E. Hadley.
Mr. W. C. Mountain.
Mr. W. H. Patchell.
Mr. J. H. Rider.
Mr. B. Welbourn.
Mr. W. B. Woodhouse.

Electro-Chemistry and Electro-Metallurgy.

Mr. W. R. Cooper.
Sir R. A. Hadfield, F.R.S.
Prof. B. Hopkinson, F.R.S.
Mr. W. M. Morrison.
Mr. J. Swinburne, F.R.S.
Capt. R. J. Wallis-Jones.

Lighting and Power.

Mr. R. A. Chattock.
Mr. J. Devonshire.
Mr. J. S. Highfield.
Mr. F. Samuelson.
Mr. W. C. P. Tapper.
Mr. B. Welbourn.

Telegraphs and Telephones.

Mr. H. G. Brown.
Mr. F. Gill.
Mr. H. H. Harrison.
Mr. W. Ll. Preece.
Mr. J. Sayers.
Sir W. Slingo.

SHIP ELECTRICAL EQUIPMENT COMMITTEE.

Mr. J. H. Collie.
Mr. B. M. Drake.
Mr. A. Henderson.
Mr. J. W. Kempster.
Mr. J. F. Nielson.
Lieut. N. W. Prangnell.
Capt. A. P. Pyne.
Mr. S. G. C. Russell.
Mr. T. A. Sedgwick.
Mr. C. H. Wordingham.

And	*Nominated by*
Mr. W. S. Abell	Lloyd's Register of Shipping.
Mr. J. T. Milton	
Mr. H. H. Berry ...	British Electrical and Allied Manufacturers' Association.
Mr. A. Boyle	Board of Trade.
Mr. W. Cross	Electrical Contractors' Association.
Mr. J. Foster King ...	British Corporation for the Survey and Registry of Shipping.
Mr. J. Lowson	Institution of Engineers and Shipbuilders in Scotland.
Mr. A. W. Stewart ...	Institution of Naval Architects.
Mr. H. Walker	N.E. Coast Institution of Engineers and Shipbuilders.

WIRING RULES COMMITTEE.

Mr. T. O. Callender.
Mr. B. M. Drake.
Dr. R. T. Glazebrook, F.R.S.
Mr. J. F. W. Hooper.
Mr. H. A. Nevill.
Mr. G. H. Nisbett.
Mr. S. G. C. Russell.
Mr. R. T. Smith.
Mr. A. L. Taylor.
Mr. C. H. Wordingham.

And	*Nominated by*
Mr. H. H. Berry ...	British Electrical and Allied Manufacturers' Association.
Mr. J. R. Dick	
Mr. J. Christie	Incorporated Municipal Electrical Association.
Mr. J. E. Edgcome ...	
Mr. W. E. Gray... ...	Cable Makers' Association.
Mr. E. J. B. Lowdon ...	Electrical Contractors' Association of Scotland.
Mr. E. T. Ruthven Murray	Incorporated Association of Electric Power Companies.
Mr. W. R. Rawlings ...	Electrical Contractors' Association.
Mr. C. P. Sparks ...	Conference of Chief Officials of London Electric Supply Companies.

ROLL OF HONOUR.

(FOURTH LIST.*)

Killed in Action.

Baker, Captain H. G.	Gloucestershire Regt.	Student
Britton, 2nd Lieut. H. E.	Royal Field Artillery	Associate Member
Brown, 2nd Lieut. H. A.	Scottish Rifles	Graduate
Bumpus, 2nd Lieut. B. E.	Northumberland Fusiliers	Associate Member
Burleigh, Lieutenant R.	Royal Flying Corps	Student
Castle, Private R. L.	Royal Warwickshire Regt.	Student
Douglas, Captain W. A.	Royal Scots	Student
Eaddy, 2nd Lieut. C. T.	North Staffordshire Regt.	Student
Edingborough, 2nd Lieut. N. D.	Middlesex Regt.	Student
Killingback, Lieutenant S. G.	Royal Engineers	Student
Organ, Lieutenant H. P.	York and Lancaster Regt.	Student
Palmer, Lieutenant J. H.	Royal Fusiliers	Associate Member
Phillips, Private T. F.	Mortar Battery	Associate Member
Rawson, 2nd Lieut. S. M.	Royal Fusiliers	Student
Reeves-Smith, 2nd Lieut. D.	Royal Engineers	Student
Rutherford, Captain J. A.	Machine Gun Corps	Associate Member
Scrivener, Sergeant R.	Royal Fusiliers	Associate Member
Ward, 2nd Lieut. C. R.	Royal Engineers	Associate Member
Wolstenholme, Lieutenant C. S.	Durham Light Infantry	Associate Member
Wood, Captain A. L.	Lancashire Fusiliers	Associate Member

Killed.

Bower, Flight Lieut. H. A.	Royal Naval Air Service	Student

Died of Wounds.

Challoner, Lieutenant T., M.C.	Royal Engineers	Associate Member
Coombs, 2nd Lieut. C. S.	Royal West Kent Regt.	Student

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* See vol. 54, pp. 64, 447, and 674.

[illegible] Infantry [illegible]
Lieut. G. M.

[illegible] [illegible] Associate
Lieut. J. S. Member

[illegible] [illegible] Associate
[illegible] Member

[illegible] [illegible] Associate
H. W. Member

MILITARY HONOURS AWARDED

(FOURTH LIST.*)

Distinguished Service Order

[illegible] [illegible] Associate
B. C. Member

"[illegible] active operations. His skill and energy in sending forward reinforcements and ammunition under very difficult circumstances tended much to the success of the operations. He had previously made a personal reconnaissance of great [illegible]

[illegible] Associate
R. A.

"For several days he cut the enemy's wire, using an obser- [illegible] he maintained communication with his [illegible] abled to cut hostile wire and frequently to [illegible]

Robertson, Major Royal Engineers Associate
[illegible]

Sparks, Captain London Regt. Member
H. C., M.C.

"[illegible] led nearly all their ammunition. With a [illegible] nearly surrounded, and thus enabled the remainder to withdraw. He was the last to leave."—*London Gazette*, 25 August, [illegible]

Military Cross

[illegible] [illegible] Associate
W. H. C. Member

"He took command of his battery with great skill and coolness. His personal courage under very heavy fire set a fine [illegible]

[illegible] Member
[illegible]

"He, with two men, established communications under very heavy fire. He displayed great courage and skill [illegible]

Donaldson, Cap- King's Royal Rifle Corps Member
tain [illegible]

"[illegible] he remained with his company, encouraging them on under [illegible]

[illegible] Associate
[illegible] Member

"[illegible]

along it under heavy fire in the night, displaying great resource, energy, and coolness. He had previously done similar good work under fire."—*London Gazette*, 25 August, [illegible]

Menzies, 2nd Lieut. Indian Infantry Associate
F. A. Member

"For conspicuous gallantry in going out, accompanied by one man, to within 100 yards of the enemy's lines and cutting the wires of six land mines. He then brought in his companion, who had been severely wounded. Three days later he was himself severely wounded."—*London Gazette*, 27 July, 1916.

Mohr, Captain Notts and Derby Regt. Associate
S. M. Member

"He showed great skill and determination in constructing a trench under very heavy fire. Later, when his company had suffered many casualties, and were under heavy artillery fire, he carried out his work with great skill."—*London Gazette*, 14 November, 1916.

Moore, 2nd Lieut. Royal Flying Corps Associate
B. J. Member

"For conspicuous gallantry and skill. He has destroyed two enemy kite balloons, one of which was being guarded by an enemy aeroplane. He has repeatedly attacked hostile aircraft, on one occasion attacking a flight of four, all of which he drove down and two of which he followed to 2,000 feet, one [illegible]"—*London Gazette*, 27 July, 1916.

Woodward, Cap- Gloucestershire Regt. Associate
tain E. H. E. Member

"He led his company in the assault with great dash until he was wounded. He displayed great coolness and courage throughout the day."—*London Gazette*, 22 September, 1916.

Bar to Military Cross.

[illegible] Captain Royal Warwickshire Regt. Graduate
H. R. L., M.C.

"He led his company with great dash in the attack, and captured a large number of prisoners. Though wounded early in the day, he carried on with great determination, till the company had captured and secured its objective."—[illegible]

Distinguished Service Cross

Riley, Lieutenant Divisional Engineers, R.N.D. Associate
T. N. Member

"In recognition of his services with the Royal Naval Division in the Gallipoli Peninsula."—*London Gazette*, 6 September, 1916.

Distinguished Conduct Medal

Kirkby, Sergt.- London Regt. Associate
Major H. M. Member

"For conspicuous gallantry and ability since the commencement of the campaign. During this period his Company had only one officer, and his powers of leadership and devotion to duty were most marked."—*London Gazette*, 10 March, 1916.

Croix de Guerre (avec Palme)

Sparks, Captain London Regt. Member
H. C., D.S.O.,
M.C.

Mentioned in Despatches

[illegible], Lieu- [illegible] Associate
tenant A. R. Member

Barker, Quarter- York and Lancaster Regt. Member
master E. A.

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* [illegible]

Bishop, Lieutenant B. L.	Royal Engineers	Student
Bollam, Lieutenant C.	Divisional Engineers, R.N.D.	Associate Member
Burchett, Sapper J. H. P.	Divisional Engineers, R.N.D.	Student
Challoner, Lieutenant T., M.C.	Royal Engineers	Associate Member
Cunningham, Major T. C.	Royal Artillery	Associate
Deedes, Lieutenant J. G.	Royal Engineers	Student
Ditmas, Captain F. I. L.	Reserve of Officers	Associate
Franks, Captain H. W.	Army Service Corps	Associate Member
Grierson, Captain R.	Divisional Engineers, R.N.D.	Associate Member
Iles, Major F. A.	Royal Engineers	Associate Member
Mousley, Major J. H., D.S.O.	Royal Engineers	Associate Member
Nelson, Warrant Officer G. D.	Royal Naval Air Service	Associate Member
Roose, Captain F. O. J.	Royal Garrison Artillery	Member
Stuart, Brig. Gen. A. M., C.B.	Royal Engineers	Member
Thornton, Lieutenant J. M.	Royal Engineers	Student

MEMBERS ON MILITARY SERVICE.

(NINTH LIST.*)

MEMBERS.

Name.	*Corps, etc.*	*Rank.*
Bishop, H. C.	Welsh Regt.	Lieutenant
Buckingham, A. O.	China British Volunteer Corps	Private
Campbell, A. S.	General List	Lieutenant
Carew-Gibson, C.	R.N.V.R.	Lieutenant
Coales, J. D., D.Sc.	Royal Flying Corps	2nd Lieut.
Combe, L. H.	Royal Horse Artillery	2nd Lieut.
Cormack, Prof. J. D.	Aircraft Equipment	Lieut.-Col.
Dashwood, E. S.	Royal Marine Artillery	2nd Lieut.
Glendenning, S. E.	Royal Engineers	Captain
Henderson, Dr. J.	Royal Engineers	Lieutenant
Herbert, A. S.	Australian Engineers	Lieutenant
Ionides, A. G.	R.N.V.R.	Lieutenant
Kilroy, W. D.	R.N.V.R.	Lieutenant
Loring, F. G.	Royal Navy	Commander
Macintyre, J., M.B.	R.N.V.R.	Staff Surgeon
O'Gorman, M. J. P., C.B.	Royal Flying Corps	Lieut.-Col.
Purves, T. F.	Royal Engineers	Captain
Pyke, L.	R.N.V.R.	Lieutenant
Redman, S. G.	Northumberland Fusiliers	Major
Saunders, E. S.	Royal Naval Air Service	Lieutenant
Scattergood, B. P.	York and Lancaster Regt.	Sergt.-Major
Scott-Atkinson, R.	British North Borneo Volunteer Rifles	Private
Stone, H. B.	Punjab Light Horse	Trooper
Thorne, G. S.	Royal Flying Corps	2nd Lieut.
Wadsworth, T.	London Electrical Engineers, R.E.	2nd Corpl.

ASSOCIATE MEMBERS.

Name.	*Corps, etc.*	*Rank.*
Archibald, R. D.	Royal Garrison Artillery	Lieutenant
Ascoli, G. H. D.	Reserve Cavalry	Lieutenant
Atkinson, A. M.	Kent (Fortress) R.E.	Lieutenant
Atkinson, C. S.	East Riding (Fortress) R.E.	2nd Lieut.
Baker, M. B.	Royal Engineers	2nd Lieut.
Baldwin, L. C.	London Electrical Engineers, R.E.	Sapper
Bill, S. H.	R.N.V.R.	Lieutenant
Blair, F.	Royal Engineers	2nd Lieut.
Booth, T. C.	Liverpool Regt.	Private
Browett, H. A.	London Electrical Engineers, R.E.	Sapper
Burge, W. S.	Northumbrian Divisional R.E.	2nd Lieut.
Cowie, J.	East Lancashire R.F.A.	Instructor
Craig, E. E.	Army Service Corps	Captain
Craig, T. I.	R.N.V.R.	Lieutenant
Curry, M. H.	Royal Engineers	2nd Lieut.
Davies, F. E.	Anti-aircraft Corps (R.N.V.R.)	Able Seaman
Davies, F. H.	Army Ordnance Dept.	Lieutenant
Davies, P. T.	Canadian Militia	Captain
Davies, W. H. St. A.	London Electrical Engineers, R.E.	Sapper
Douglas, C. H.	Royal Flying Corps	Major
Dransfield, T. E.	R.N.V.R.	Lieutenant
Durant, J. H.	Australian Engineers	Lieutenant
Eaton, G. H.	Calcutta Light Horse	Trooper
Eunson, D. M.	City of Edinburgh (Fortress) R.E.	Sapper
Evans, T. C.	Manchester Regt.	Private
Evans, T. K.	South Midland R.F.A.	Lieutenant
Ferguson, John	Royal Flying Corps	2nd Lieut.
Fidoe, J. W.	Inns of Court O.T.C.	Private
Field, G. K.	Royal Flying Corps	Captain
Fox, P. S.	R.N.V.R.	Lieutenant
Fraser, J. W.	Royal Naval Air Service	Air Mechanic
Georgi, W. C. H. M.	Durham (Fortress) R.E.	Lieutenant
Golden, W. T.	R.N.V.R.	Sub-Lieut.
Golding, R. A.	Australian Engineers	Sapper
Gray, C. F.	Canadian Militia	Captain
Gray, E. B.	London Electrical Engineers, R.E.	Sapper
Green, H.	Royal Engineers	Cadet
Green, H. H. R.	R.N.V.R.	Lieutenant
Gresswell, H. H.	Army Ordnance Dept.	Lieutenant
Hamilton, F. T.	Tyne Electrical Engineers, R.E.	2nd Lieut.
Hill, C. W.	R.N.V.R.	Lieutenant
Hirtzel, C. H. A.	Royal Flying Corps	Captain
Horsley, J. A. B.	R.N.V.R.	Eng.-Lieut.
Hounsfield, F. C.	Army Service Corps	2nd Lieut.
Hume, D. C. M.	R.N.V.R.	Lieutenant
Hutchison, E.	Australian Artillery	Sergeant
Jaffe, A. D.	London Regt.	Captain
Johnson, S.	Australian Pioneers	2nd Lieut.
Joseph, H.	Royal Engineers	2nd Lieut.
Keelan, R. E.	Royal Engineers	Lieutenant
Kefford, H. W.	Royal Artillery	Cadet
Lambert, E. A.	Royal Engineers	2nd Lieut.
McCallum, A. H. S.	R.N.V.R.	Lieutenant
MacDougall, J. K.	Australian Imperial Force	
Mackrill, W. S.	R.N.V.R.	Chief Petty Officer
Markes, A. S.	London Electrical Engineers, R.E.	Sapper
Mayer, J. W.	Royal Engineers	Staff Sergt.

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* See vol. 53, pp. 199, 326, 388, and 857, and vol. 54, pp. 121, 403, 518, and 675.

Associate Members—continued

[illegible]	[illegible]	[illegible]
[illegible]	Royal Field Artillery	2nd Lieut.
[illegible]	[illegible]	Lieutenant
Merritt, F. H.	R.N.V.R.	[illegible]
[illegible]	[illegible]	1st Class Air Mechanic
Miller, F. S.	[illegible]	2nd Lieut.
[illegible]	Royal Naval Air Service	
[illegible]	Royal Naval Air Service	[illegible]
[illegible]	[illegible]	Captain
[illegible]	[illegible]	[illegible] Mechanic
Perrin, E. S.	Royal Flying Corps	2nd Lieut.
Pitkeathly, J. S., C.V.O.	General List	Major
[illegible]	Army Service Corps	2nd Lieut.
Price-Hughes, H. A.	Glamorgan (Fortress) R.E.	[illegible]
Rattray, C. G.	R.N.V.R.	Lieutenant
Rayment, A. C.	Australian Pioneers	Corporal
Reid, S. B.	Royal Flying Corps	2nd Class Air Mechanic
[illegible]	Royal Welsh Fusiliers	Private
Roget, S. R.	Anti-Aircraft Corps (R.N.V.R.)	
Sadd, J. A.	Staff	[illegible]
Sharp, E. E.	Army Ordnance Dept.	Lieutenant
[illegible]	[illegible]	Captain
Short, E. A.	[illegible]	Captain
Smeeton, E. E.	London Electrical Engineers, R.E.	Sapper
Smith, A. C.	Army Ordnance Dept.	Lieutenant
Smith, D.	Royal Flying Corps	2nd Lieut.
Stephens, J. N.	Royal Flying Corps	2nd Lieut.
Stone, A. A.	Army Service Corps	2nd Lieut.
Trippe, C. F.	Royal Engineers	2nd Lieut.
Troughton, J. A.	[illegible] R.E.	Sapper
[illegible]	General List	Captain
[illegible]	Royal Garrison Artillery	2nd Lieut.
Tweedie, M. G.	[illegible]	Lieutenant
[illegible]	Royal Flying Corps	2nd Class Air Mechanic
Wakeford, L. T.	British North Borneo Volunteer Rifles	Private
Warren, J.	Army Ordnance Dept.	Lieutenant
[illegible]	R.N.V.R.	Lieutenant
Wood, P.	R.N.V.R.	Lieutenant

[illegible]

[illegible]	[illegible]	*Rank*
[illegible]	Royal Garrison Artillery	
Coaster, C. S.	London Electrical Engineers, R.E.	Sapper
[illegible]	[illegible] R.E.	Sapper
[illegible]	R.N.V.R.	[illegible]
[illegible]	[illegible]	Lieutenant
Keave, A. M.	[illegible]	Major
[illegible]	[illegible] Engineers	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Lieutenant
[illegible]	[illegible]	[illegible]
Webber, W. J.	[illegible]	2nd Lieut.

Graduates

[illegible]	[illegible]	*Rank*
Barr, T. H.	Military Representative for Renfrewshire	Major
Fellowes, H. S.	R.N.V.R.	Sub-Lieut.
Hill, S. M.	Royal Navy	Eng. Room Artificer
Howard, T. W.	Royal Flying Corps	Air Mechanic
Jockel, L. M.	London Electrical Engineers, R.E.	[illegible]
[illegible]	Army Service Corps	Lance-Corpl.
Miller, J.	Lowland Divisional R.E.	[illegible]
Molyneux, M. J. H.	Royal Naval Air Service	Sub-Lieut.
Munro, J. W. W.	Royal Flying Corps	2nd Class Air Mechanic
Murray, J. B.	Royal Engineers	2nd Lieut.
Norman, H.	London Electrical Engineers, R.E.	Corporal
Richards, E. A.	Royal Flying Corps	2nd Lieut.
Rintoul, W.	Northern Signal Service, R.E.	Lieutenant
[illegible]	Royal Flying Corps	2nd Class Air Mechanic

STUDENTS.

[illegible]	East Anglian Divisional R.E.	Lieutenant
Allan, G. A.	Royal West Kent Regt.	Private
Barlow, L. M.	Royal Flying Corps	2nd Lieut.
Binnie, R. D.	Royal Marine Artillery	2nd Lieut.
Cable, W. H.	Royal Engineers	2nd Lieut.
Caspar, F. A. E.	Royal Engineers	Sapper
Charley, R. M.	Royal Flying Corps	2nd Lieut.
Charnley, J. H.	Army Service Corps	2nd Lieut.
Colburn, F.	Royal Engineers	Pioneer
De Pomeroy, N. R.	Royal Flying Corps	2nd Lieut.
Dancy, W.	[illegible]	2nd Lieut.
Duckworth, E. H.	[illegible] R.E.	2nd Lieut.
[illegible]	Australian Infantry	Sergeant
Dunnill, F.	London Electrical Engineers, R.E.	Sapper
Essden, G. H.	London Electrical Engineers, R.E.	[illegible]
Exley, W.	Tyne Electrical Engineers, [illegible]	Sapper
Fisher, D'a. G.	R.N.V.R.	Sub-Lieut.
Fisher, R. E. S.	Royal Engineers	Cadet
Flint, E. W.	Royal Flying Corps	[illegible] Mechanic
Gibson, William	Royal Engineers	2nd Corpl.
Gillett, B. M.	Royal Garrison Artillery	Gunner
Goodwin, J. H.	Friends Ambulance Unit	Motor Eng.
Hall, C. L.	Royal Engineers	Lieutenant
Hancock, L. J.	Royal Engineers	Lieutenant
Hindom, H. J.	[illegible]	
Hyde, C. L. G.	Royal Engineers	Sapper
Lee, J. F.	[illegible]	2nd Class Air Mechanic
Leys, H. H.	Lowland R.F.A.	Lieutenant
Linay, R. E. M.	[illegible]	
McCall, G. W.	Royal Naval Air Service	Able Seaman
Mathias, E. L. A.	[illegible]	Sub-Lieut.
Murray, B. M.	London Electrical Engineers [illegible]	Sapper
[illegible]	[illegible] R.E.	[illegible]
Parker, V. H. G.	[illegible]	2nd Lieut.
Parkinson, A. M.	[illegible]	[illegible]

STUDENTS—*continued.*

Name.	*Corps, etc.*	*Rank.*
Robinson, D. H.	South Staffordshire Regt.	Lieutenant
Ross, V.	Royal Engineers	
Rowe, B.	Manchester Regt.	2nd Lieut.
Senior, R. C.	Royal Naval Air Service	Air Mechanic
Slingerland, J. F.	London Electrical Engineers, R.E.	Sapper
Smith, W. K.	British Red Cross	Orderly
Smyth, H. W. S.	Royal Engineers	Lieutenant
Tilson, H. S.	London Electrical Engineers, R.E.	Sapper
Walker, E.	London Electrical Engineers, R.E.	Sapper
Warden, E. A.	Canadian Field Artillery	
Wardrop, G. G.	London Electrical Engineers, R.E.	Sapper
Webb, R. J.	Kent (Fortress) R.E.	2nd Lieut.
Winkley, S. H.	Inns of Court O.T.C.	Private
Wormull, C. F.	Royal Flying Corps	2nd Lieut.
Young, R.	South Lancashhire Regt.	2nd Lieut.

INSTITUTION STAFF.

Ashford, H. J.	Army Service Corps	Private
Clinch, L. W.	Army Service Corps	Driver
Corthesy, J.	London Electrical Engineers, R.E.	Sapper
Crowther, W. V.	Royal Garrison Artillery	Cadet
Grant, F.	Royal Flying Corps	2nd Class Air Mechanic
Harris, F. C.	Royal Engineers	Sapper
Hedges, F. H. W.	Army Veterinary Corps	Private
Herring, S. V.	London Regt.	Private
Nunn, H. J.	Honourable Artillery Company	Sergeant
Skinner, C. W.	Honourable Artillery Company	Private
Tillott, G.	Rifle Brigade	Private

PROMOTIONS, TRANSFERS, ETC., OF MEMBERS ON MILITARY SERVICE.

(FIFTH LIST.*)

MEMBERS.

Name.	*Corps, etc.*	*Rank.*
Barber, C.	Royal Flying Corps	Captain
Barker, E. A.	Royal Engineers	Captain
Hamilton, C. N. M.	Royal Garrison Artillery	Lieutenant
Marconi, G.	Italian Navy	Captain
Paterson, S.	Royal Engineers	Lieutenant
Pyne, A. P.	Tynemouth R.G.A.	Captain
Sparks, H. C., D.S.O., M.C.	London Regt.	Major
Taylor, W. T.	Royal Flying Corps	Captain

ASSOCIATE MEMBERS.

Abell, C. E.	London Electrical Engineers, R.E.	Lieutenant
Aldous, F. C.	Machine Gun Corps	Major
Allingham, G. C.	Royal Engineers	2nd Lieut.
Archer, J. O.	Royal Flying Corps	2nd Lieut.
Ardern, A.	Royal Engineers	2nd Lieut.
Baillie, T. C.	Royal Garrison Artillery	Captain
Barney, L. W.	Royal Flying Corps	2nd Lieut.
Baumann, F. C.	London Electrical Engineers, R.E.	2nd Lieut.

ASSOCIATE MEMBERS—*continued.*

Name.	*Corps, etc.*	*Rank.*
Bazalgette, H. L.	London Electrical Engineers, R.E.	Lieutenant
Birch, F.	R.N.V.R.	Lieutenant
Bland, C. R.	London Regt.	Captain
Boxall, G. F.	Royal Engineers	2nd Lieut.
Brazier, C. C. H.	Indian Infantry	2nd Lieut.
Brewis, J. M.	Army Ordnance Dept.	Captain
Browne, W. S.	London Electrical Engineers, R.E.	2nd Lieut.
Bruce, R.	Royal Engineers	Captain
Bullpitt, K. D.	Essex Regt.	2nd Lieut.
Carty, S. W.	Army Service Corps	Captain
Clark, E. V.	Australian Engineers	Lieutenant
Clarke, W. G.	Royal Engineers	Major
Clayton, A. E.	London Electrical Engineers, R.E.	Lance-Corpl.
Clayton, B. C.	Royal Naval Air Service	Flight-Lieut.
Colbeck, P.	Northumberland Fusiliers	Major
Cunliffe, J. G.	Manchester Regt.	Captain
Davies, L. H.	Royal Garrison Artillery	Lieutenant
Davis, A. A.	South African Infantry	Private
Dermer, L. H.	West Riding Divisional R.E.	Captain
Dobell, H.	R.N.V.R.	Lieutenant
Dodds, J. W.	Army Service Corps	Captain
Eastman, H. A.	Royal Engineers	2nd Lieut.
Edgar, E. J.	Divisional Engineers, R.N.D.	Sergeant
Edmonds, C. H. W.	Royal Engineers	Captain
Edwards, E. A.	Royal Engineers	Lieutenant
Edwards, W. G.	Tyne Electrical Engineers, R.E.	Lieutenant
Francies, R.	London Electrical Engineers, R.E.	2nd Lieut.
Franks, H. W.	Army Service Corps	Captain
French, W. W. E.	Royal Engineers	Lieutenant
Friend, R. H.	Royal Engineers	2nd Lieut.
Frost, P. B.	Royal Engineers	Lieutenant
Gardner, M. R.	Royal Navy	Warrant Electrician
Gill, V. W.	Royal Sussex Regt.	2nd Lieut.
Gilling, A. C.	Royal Flying Corps	Captain
Goble, F.	London Electrical Engineers, R.E.	2nd Lieut.
Graty, T. R.	Royal Engineers	Lieutenant
Graves, E.	Indian Army Reserve of Officers	2nd Lieut.
Hann, C. S.	London Electrical Engineers, R.E.	2nd Lieut.
Hartley, G.	Lancashire Fusiliers	2nd Lieut.
Hayward, C. H.	Royal Naval Air Service	Flight-Lieut.
Hoyle, B.	R.N.V.R.	Lieutenant
Huntley, C. G.	Tyne Electrical Engineers, R.E.	Lieutenant
Ingram, G.	Royal Engineers	2nd Lieut.
Johnson, A. L.	Royal Flying Corps	2nd Lieut.
Johnson, W. G.	Royal Engineers	Lieutenant
Jones, J. G.	Royal Fusiliers	Captain
Kirkby, H. M.	Army Ordnance Dept.	Captain
Leak, B. W.	Royal Garrison Artillery	2nd Lieut.
Le Feuvre, C. G.	Army Service Corps	Sergt.-Major
Leggett, B. J.	Royal Berkshire Regt.	2nd Lieut.
Leslie, R. C.	Army Cyclist Corps	Lieutenant
Loughlin, H. J.	Royal Engineers	2nd Lieut.
McMahon, V. H. M.	Army Service Corps	2nd Lieut.
Mann, F. H.	R.N.V.R.	Lieutenant
Mann, R. R. G.	Royal Engineers	Lieutenant

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* See vol. 54, pp. 307, 404, 579, and 675.

[illegible]

[illegible]	[illegible]	*Rank.*
[illegible]	[illegible] R.E.	[illegible]
[illegible]	[illegible] R.E.	Captain
[illegible]	[illegible] R.E.	[illegible]
[illegible]	[illegible] R.E.	2nd Lieut.
Parkinson, J.	[illegible]	[illegible]
Pearson, H. H.	[illegible]	2nd Lieut.
Pope, W. G. T.	[illegible]	[illegible]
Porter, T. Y.	[illegible]	Lieutenant
[illegible]	[illegible]	Lieutenant
[illegible]	[illegible]	Major
Sargent, G. H.	[illegible]	Lieutenant
Seeley, C. G.	[illegible]	Lieutenant
[illegible]	[illegible]	2nd Lieut.
Sinclair, A.	[illegible]	2nd Lieut.
Smith, B. H.	[illegible]	Lieutenant
Sparks, A. C.	[illegible]	Captain
Suggate, C. F. D.	[illegible]	Captain
Symmes, H. C.	South African Infantry	[illegible]
[illegible]	[illegible] R.E.	Lieutenant
[illegible]	[illegible]	[illegible]
[illegible]	Royal Naval Air Service	Flight-Com.
[illegible]	[illegible]	Corporal
[illegible]	Royal Engineers	Lieutenant
[illegible]	[illegible] Officers	2nd Lieut.

[illegible]

[illegible]	Army Ordnance Corps	Sergt.-Major
[illegible]	[illegible]	[illegible]
[illegible]	R.N.V.R.	Sub-Lieut.
[illegible]	Army Ordnance Dept.	Captain

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2nd Lieut.
[illegible]	[illegible]	Lieutenant
[illegible], A.	[illegible]	Captain
[illegible]	[illegible]	Captain
[illegible]	[illegible]	Lieutenant
[illegible]	[illegible]	Captain
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible]	[illegible]	Captain
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Sapper
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

Name.	*Corps, etc.*	*Rank.*
Bishop, B. L.	Royal Anglesey R.E.	Captain
Bramwell, H. P.	Royal Flying Corps	2nd Lieut.
[illegible]	[illegible]	Captain
[illegible]	Royal Warwickshire Regt.	Lieutenant
[illegible]	Royal Horse Artillery	2nd Lieut.
Cosserat, E. W.	[illegible]	2nd Lieut.
Damant, E. L.	Royal Engineers	2nd Lieut.
[illegible]	London Electrical Engineers, R.E.	[illegible]
Derry, C.	Army Service Corps	[illegible]
Driver, E. T.	Royal Flying Corps	2nd Lieut.
[illegible]	Royal Naval Air Service	[illegible]
Gwyther, H. J.	Manchester Regt.	[illegible]
Hart, L. V.	[illegible]	Lieutenant
Headsward, H.	Royal Engineers	2nd Lieut.
Hews, C. J.	London and Tyne Electrical and Mechanical Co., R.E.	2nd Lieut.
[illegible]	West Yorkshire Regt.	Lieutenant
Hudson, H.	Canadian A.S.C.	Lieutenant
Hughes, P. R.	Royal Field Artillery	Lieutenant
[illegible]	R.N.V.R.	Lieutenant
Jones, J. W.	[illegible] R.E.	Lieutenant
Knight, C. S.	London Electrical Engineers, R.E.	2nd Lieut.
Leeson, B. H.	Divisional Engineers, R.N.D.	Sergeant
Leeves, A. H.	Royal Engineers	Lieutenant
Leishman, G. A. B.	Royal Field Artillery	Lieutenant
Lisle, A.	Royal Engineers	2nd Lieut.
McDougald, L. A.	[illegible]	Lieutenant
Macpherson, A. W. R.	Royal Engineers	Lieutenant
Martin, G. E.	Royal Garrison Artillery	Lieutenant
[illegible]	Royal Field Artillery	Captain
Mold, L. E.	Royal Engineers	Lieutenant
Mould, James	Royal Garrison Artillery	[illegible]
Page, J. J.	Royal Field Artillery	Lieutenant
Peter, L. H.	[illegible]	2nd Lieut.
Pullan, A. H.	[illegible]	2nd Lieut.
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]chester Regt.	[illegible]
Riley, H.	[illegible]	Lieutenant
Ripley, H. S.	[illegible] R.E.	[illegible]
Ross-Bain, G.	Manchester Regt.	Lieutenant
Shuter, E. J.	Royal Marines	Lieutenant
Sizer, N.	[illegible]	Lieutenant
Smith, L. C. R.	[illegible]	[illegible]
Stainer, W. W.	[illegible]	[illegible]
[illegible]	[illegible] R.E.	2nd Lieut.
Stern, D. C.	Royal West Kent Regt.	Major
Turton, T. C.	[illegible]	2nd Lieut.
[illegible]	Royal Naval Air Service	[illegible]
Williams, C. S.	[illegible]	2nd Lieut.
Windle, J. B.	Lancashire and Cheshire R.G.A.	Captain
Wooler, L. S.	[illegible]	[illegible]

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THE PARALLEL OPERATION OF ELECTRIC POWER STATIONS.

By JOHN S. PECK, Member.

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In Great Britain many municipalities have their own electric supply systems, and in several cases there are separate stations in the same city for traction and for power and lighting. In London there are very many independent stations, and throughout the country there are a considerable number of supply companies which furnish energy within certain definite areas. The possibility of linking up the stations in the different districts has often been considered, but it is only recently that the full advantages have been generally appreciated and that the problem has been attacked along broad lines.

It is not proposed in this paper to discuss the commercial questions involved in linking up, but to point out some of the engineering problems and to indicate what types of apparatus are available and the conditions under which they may be used.

Fortunately the great majority of stations in this country generate three-phase current at 50 periods, so that the problem of interconnecting is relatively simple. But there are a number of large systems which generate at 25 and 40 periods, several generate at 60 periods, two large stations generate at 33 periods, while a considerable number generate at other frequencies. These last are principally single-phase systems. The problem of linking up systems of different frequencies is much more complicated than that of linking up systems of the same frequency, and each particular case requires careful consideration in order to determine the best method to adopt.

ALTERNATORS IN PARALLEL.

When two alternating-current generators having the same number of poles and the same rating are operated in parallel, they must, of course, run at exactly the same speed, and, if they are to divide the load equally, it is essential that the two engines (or turbines) driving them should have the same speed regulation, i.e. the same drop in speed from no load to full load. If one engine should have a regulation of 2 per cent and the other of 4 per cent, then (assuming the regulation curve to be a straight line) with full load on one generator there would be only half load on the other. In other words, the load carried by the generator is determined by the amount of steam admitted to the engine, and not by the adjustment of the field strength of either machine, i.e. the load depends on the governor and not on the position of the field rheostat. Any two machines may be made to divide the load in any desired proportion by proper adjustment of the steam supply, while adjustments of the field rheostats simply cause wattless currents to flow between the generators. The effect of this current is to strengthen the field of the under-excited generator and to weaken that of the over-excited generator; thus the voltage across the two remains equal.

The operation of two or more stations in parallel is simply the operation of two or more groups of generators in parallel, and the conditions are similar to those involved in operating two single generators in parallel, except for the fact that the interconnecting line possesses inductance and resistance. For all ordinary cases the resistance and inductance may be neglected, but the matter is treated in a general way in Appendix 1.

STATIONS OF THE SAME FREQUENCY, VOLTAGE, AND PHASE.

When the stations to be linked up have the same frequency, voltage, and phase, the only interconnecting link required is a cable with the necessary switches, etc., for connecting together the busbars of the two stations. It often happens, however, that the normal voltages of the two stations are not exactly equal, and it may be required to vary the voltage of either station independently of that of the other. For this reason it is desirable to have some form of voltage regulator in at least one of the stations, otherwise, when voltage adjustments are attempted, heavy wattless currents will flow between the stations and the voltages on the two systems will remain equal, except for the difference due to the drop of pressure in the cable.

The regulator may be either of the step-by-step or of the induction type.

Fig. 1 shows a diagram of connections which may be used when a step-by-step regulator is adopted. A, A, are [illegible] the maximum load which will have to [illegible]

[illegible] usually be adjusted to give approximately this condition.

With two stations A and B, the following cases will be [illegible]

(a) [illegible]
[illegible] loads on the two stations.
(b) [illegible]

[illegible]

each station and the connecting feeder must carry half the difference in load.

Example.—Assume each station to have a capacity of 10,000 kw., and that there is a load on A's busbars of 15,000 kw., and on B's of 5,000 kw.; then the total load on the stations equals 20,000 kw. Each station will supply 10,000 kw. Therefore the load on the interconnector equals 10,000 − 5,000 = 5,000 kw., i.e. the load on the interconnector equals one-half of the difference in load on the busbars of the two stations.

[illegible]

This case will be similar to the preceding one, except that instead of the total load being divided equally between [illegible]

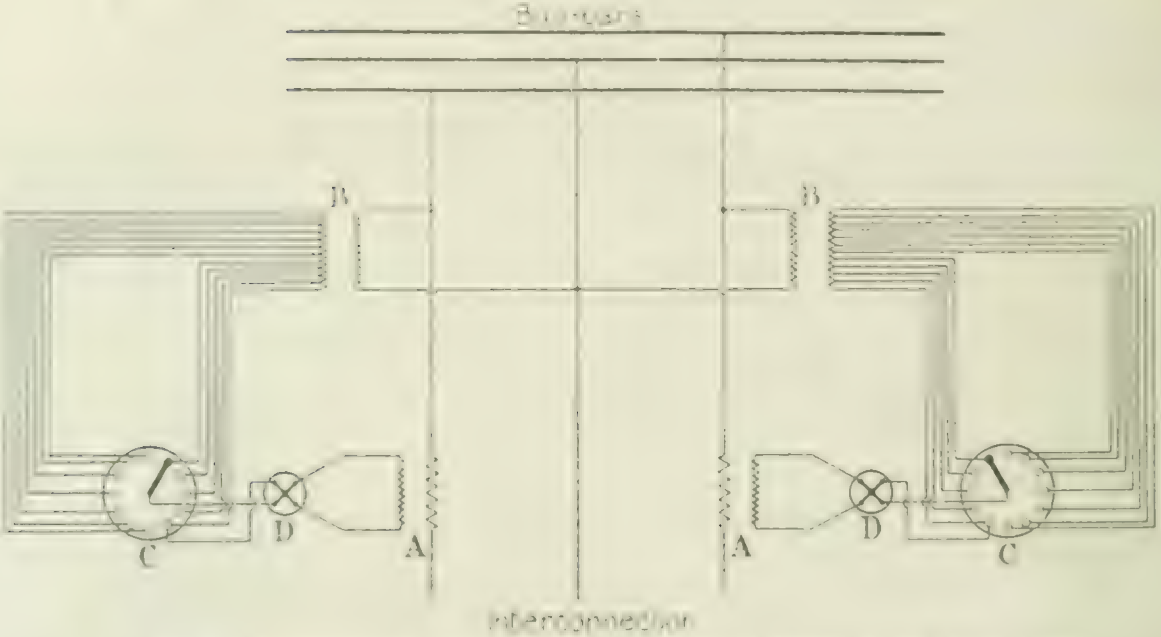


Fig. [illegible]

[illegible] Knowing the load on the busbars and on the generators of each system, the load on the interconnector is known at once.

[illegible] a capacity of 5,000 kw., i.e. (Capacity of A) : (Capacity of B) = 2 : 1. The load on each set of busbars = 6,000 kw. [illegible] load, A delivers 6,666 kw., and B 3,333 kw., therefore the [illegible]

[illegible] on the interconnecting line. If the loads are steady the [illegible] minimum or any other desired load on the interconnector, but where violent fluctuations occur manual adjustments of the governor are impossible, and account must be taken of this fact when designing the interconnecting line.

Where the engine governors of two systems are set for different speed regulations, they will divide the total load, not in proportion to their generating capacities, but in direct proportion to their ratings and in inverse proportion to their speed regulation, assuming a straight-line speed drop. Thus, if station A has a rated capacity of 10,000 kw. and B 5,000 kw., while A drops 2 per cent and B 4 per cent in speed from no load to full load, the two stations will share the total load in the proportion of (10/5) × (4/2) = 4, i.e. A will deliver four times the load of B. If the regulation of A is 4 per cent and that of B 2 per cent, then the proportion would be (10/5) × (2/4) = 1, i.e. the two stations would deliver equal loads. This would be a very dangerous condition, as B would be heavily overloaded before full load was reached on A. This simply confirms what is well known in operating machines in parallel, namely, that when the regulation cannot be made equal on two machines, the larger one should have the closer regulation.

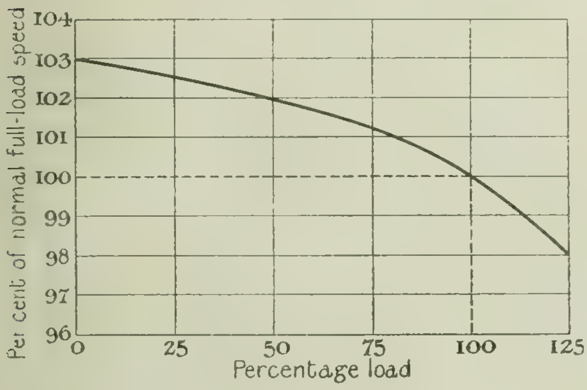


FIG. 2*a*.—Speed-regulation curve for turbine or reciprocating engine with throttle governing.

Thus it is a simple matter to determine the distribution of load between two stations in parallel, provided the operating conditions and the speed regulation are known. The same methods may be used where there are several stations in parallel, and as soon as the loads on the different stations have been determined the load on the different interconnectors may be found.

In the above considerations it has been assumed that the drop in engine speed is proportional to the load, but, as a rule, the regulation curve is not exactly a straight line.

In a reciprocating engine, or turbine, with throttle-governing only, the speed curve is usually of the shape shown in Fig. 2*a*, while Fig. 2*b* shows approximately the curve for a steam turbine with "nozzle cut-out" governing. This curve approximates to a straight line more closely than does that of Fig. 2*a*, and it is evident that the greater the number of nozzle stages the more closely does the curve approach to a straight line. It will be noted that characteristics of curve 2*a*, and of each section of curve 2*b*, are a flat portion for the lower loads and a drooping position for the higher loads. The shape of curve shown in Fig. 2*a* is desirable for parallel operation, because, if the governors are not set exactly alike, the machine taking the greater load will tend to drop more rapidly in speed and thus shift its load to the machine which is operating on the flatter part of the speed curve. In the case of nozzle cut-out governing, it may happen that the machine taking the greater load reaches the straight part of one section of the curve while the other machine is on the drooping part of another section. In this case the more heavily loaded machine will tend to take still more load. This has one advantage, however, as a turbine works more economically on the drooping portion of any section of the curve than on the flat portion.

Although the speed curve may not be exactly a straight line, the distribution of load, as calculated by the methods given above, is sufficiently close for all practical purposes. In the actual parallel operation of alternators in a station, the loads are seldom divided exactly in proportion to the ratings of the different machines but shift from one set to another with variations in the external load, depending on the governor adjustments. This causes, however, no trouble in the station as long as the sets share their loads properly at the full output of the station, and hand adjustment of the governors is necessary from time to time. In the operation of stations in parallel exactly the same problems are involved, and there should be no more trouble than in operating different generators in the same station in parallel provided that the interconnecting link is made of sufficient capacity to take care of any discrepancies in load adjustments due to governor peculiarities.

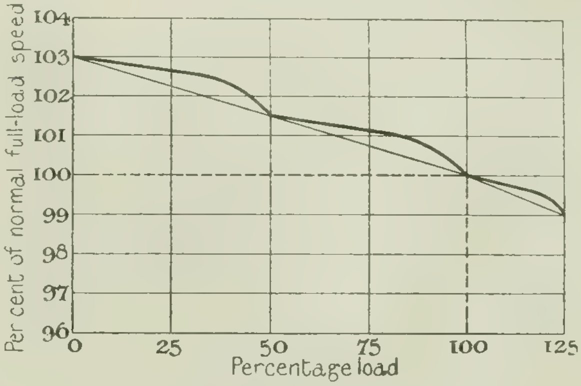


FIG. 2*b*.—Speed-regulation curve for turbine with combined throttle and nozzle cut-out governing.

It is, of course, possible that in certain cases an automatic regulator could be used for adjusting the governor valves according to the load on the interconnector, but this is a refinement which is not likely to be required, as satisfactory operation can almost always be obtained without such a device.

EARTHED NEUTRALS.

It is becoming standard practice in all large generating stations to earth the neutral point of the system. Where the busbars of two earthed systems are directly coupled together there may be heavy high-frequency currents flowing through earth between the stations, and these currents may cause trouble in telephone and telegraph

[illegible]

(a) One station only may be earthed. In this case arrangements could be made so that when the [illegible]

[illegible] system to the earth on the other system, *i.e.* both systems would have a common earthed point.

(c) Transformers could be inserted in the interconnecting line.

(d) Reactances or resistances could be placed in the earth connection to limit the earth currents to a negligible value.

[illegible] VOLTAGE OR PHASE.

Where the stations are of the same frequency but of different phase or voltage, it is necessary to introduce transformers into the interconnector. The voltage and phase transformation is made, where such is required, in the same transformers.

Fig. 3 shows the diagram of connections used for the transformers of a 4,000-kw. interconnector between two stations in London, one generating 2,200 volts two-phase and the other 11,000 volts three-phase. For varying the voltage between the two stations step-by-step regulators are used. A [illegible]

Apart from the introduction of transformers, the operating conditions for stations having different voltages or phases are exactly the same as when the stations have the same voltage and phase, except where it is required to link up a single-phase system with a two- or three-phase system. If it is desired to distribute the load equally on all phases of the three-phase or two-phase system, rotating apparatus is required. This may take the form of a motor-generator or of what is known as a phase converter.

Several designs of phase converters have been proposed, but they all utilize the well-known fact that if one phase of a two- or three-phase machine be supplied with current and the rotor be brought up to speed, then two-phase or three-phase current can be supplied from the four or three terminals of the motor. Various schemes are used for balancing the phases, but as this paper does not deal with [illegible] of converting apparatus, the matter will not be [illegible] further.

This type of converting plant is used on the Norfolk and Western Railway in America for converting the single-phase trolley current into three-phase current for the motors on the locomotives. When running down grade, the three-phase motors regenerate and supply single-phase current to the trolley through the converter. Similar plant is being installed in the substations of a [illegible] system for converting from three-phase to single-phase for supplying the trolley circuit.

[illegible]

When two stations of different frequencies are to be linked [illegible] type. This will usually take the form of a motor-generator, but in certain cases where continuous current is required it may be advantageous to use a rotary converter for changing from one frequency to continuous current, and another to change from continuous current to the other frequency. Under this condition it is of course possible to use both rotary converters for supplying continuous-current load from the two different systems. This condition will be considered later on.

The cost of a motor-generator is comparatively high, and while it is desirable to keep down its size to correspond to the load which it is desired to transmit from one station to the other, its capacity must also be chosen with reference to the load it may have to transmit under abnormal conditions, and the choice of the type of converting plant will be governed largely by this consideration.

The motor-generator for frequency transformation may be either of the following two types :—

Synchronous motor and synchronous generator—called "synchronous motor-generator."
Induction motor and synchronous generator—called "induction motor-generator."

Each set has certain advantages and disadvantages.

SYNCHRONOUS MOTOR-GENERATOR.

Since each machine of the set must run in synchronism with the system to which it is connected, the two systems must run at speeds which are definitely fixed with reference to each other. In other words, the two systems are locked together through the motor-generator, which acts as a perfectly rigid coupling, and it is the strength of this coupling with reference to the loads likely to be thrown on it which requires careful consideration in all cases.

Since the synchronous set locks the two systems in step, the transfer of energy from one system to the other will be governed by the same conditions as when the systems are of the same frequency and paralleled by a direct cable connection. Thus the loads likely to be thrown on the converting set may be calculated in the same way as described above for systems of the same frequency.

[illegible]

(1) It is reversible and can supply energy in either direction without change from the normal speed ratio.

(2) The motoring machine can be run at unity power factor, or even with a leading power factor, and thus assist in improving the power factor of the system. The generating machine may be run with an over-excited field and so reduce the lagging current carried by other generators on the system.

[illegible]

(1) The set, acting as a rigid coupling, forces the two systems to run at a fixed speed ratio and is therefore subject to heavy overloads under certain conditions.

(2) Each machine must be synchronized with its own system, an operation requiring some skill, especially with certain ratios between the numbers of poles.

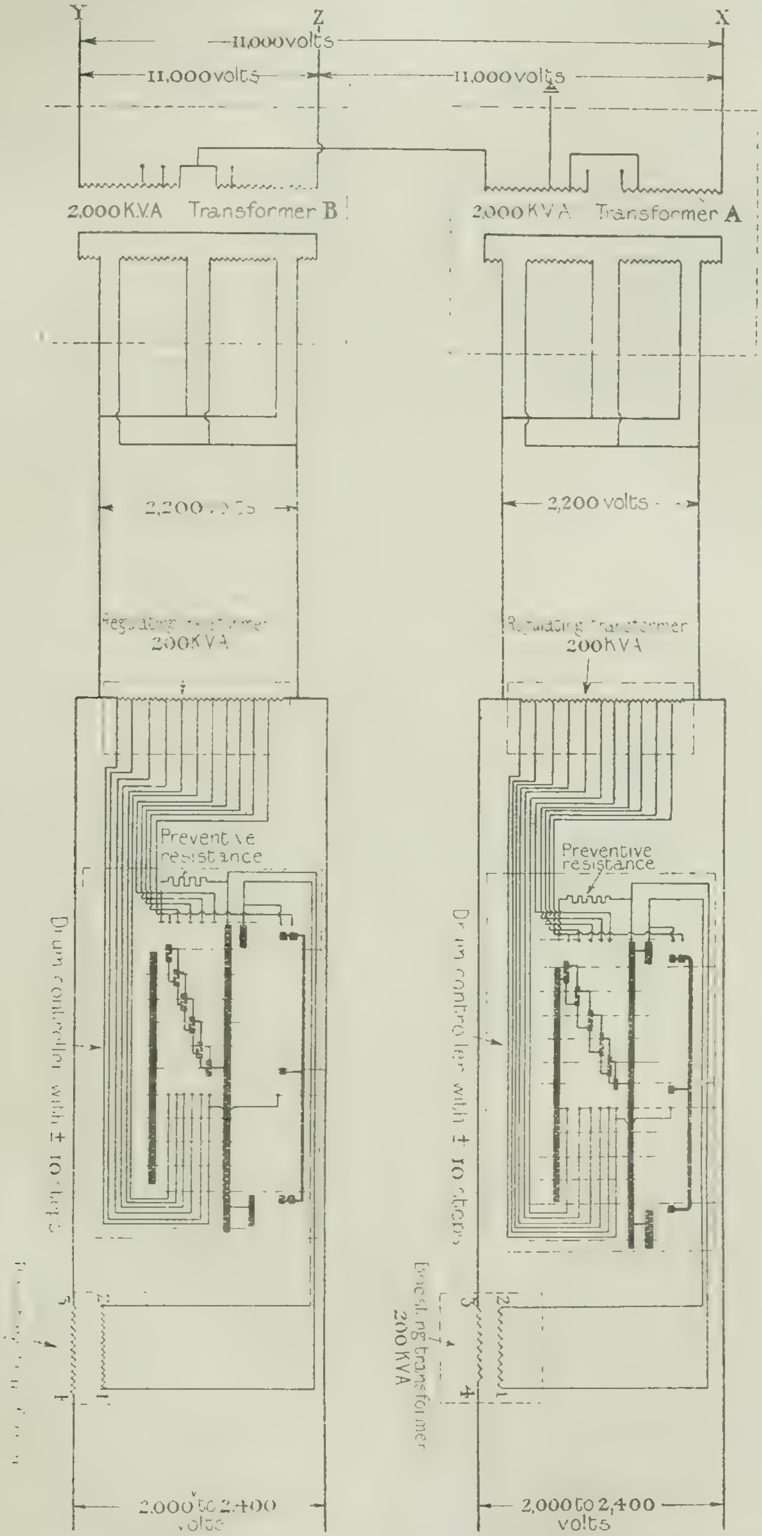


Fig. 3.—Diagram of connections of transformers and regulators in 4,000-kw. interconnector between 2,200-volt two-phase system and 11,000-volt three-phase system in London.

(7) When two motor-generators are operated in parallel, special arrangements are required in order to synchronize an unloaded set with one under load.

[illegible]

Where an induction motor and a synchronous generator are used, the induction motor does not run in synchronism with the supply system, but runs slightly below synchronous speed; the difference between its speed and synchronous speed (expressed as a percentage of the synchronous speed) is known as the slip, and this varies directly with the load transmitted. Furthermore, this slip may be regulated by adjusting the amount of resistance in series with the secondary number. The induction set may be likened to a slipping coupling between two prime movers where the amount of slip depends on the load transmitted

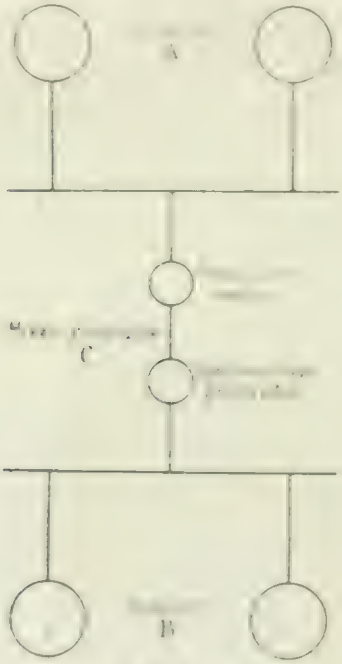


Fig. 4.

so that they are not required to operate at exactly the same speed.

The simplest way of understanding the working of the [illegible] is to take a [illegible] example. Assume two stations A and B as in Fig. 4. Let the capacity of A be [illegible] kw., that of B [illegible] kw., and that of the motor-generator 1,000 kw. Assume the speed regulation of A and B to be each equal to 2 per cent, and the slip of the induction motor at full load to be 2 per cent. If there be no load on either station, and they are each running at normal speed, the set will run at synchronous speed and will transmit no load. If a load of [illegible] kw. be put on B's busbars, the speed of B will tend to drop 2 per cent, and if A is assumed kept at normal speed, 1,000 kw. will be transmitted through the motor-generator. But the load on A through the motor-generator will cause the speed of A to drop slightly, and since the load on B is now reduced by the amount supplied by A, the speed of B will not be reduced by quite 2 per cent, and the slip of the motor-generator being less than 2 per cent, it will transmit less than 1,000 kw. To be exact it will be 770 kw. A method for determining the exact load on the frequency changer under different conditions will be found in Appendix 2. If the load be increased to 10,000 kw. the drop in speed of B will be doubled and the motor-generator will transmit approximately 1,000 kw., etc.

If with B giving a load of 5,000 kw., and the motor-generator transmitting 770 kw., the load on A be [illegible] increased, the speed of A will fall and the load transmitted from A to B will be reduced, until when the speeds of the two sets have dropped by the same percentage there will be no energy transmitted through the motor-generator.

As is well known an induction motor will act as a generator if it is driven at a speed above the synchronous speed of the system to which it is connected. The load it will deliver as a generator when running at a certain speed above synchronism is the same as the load it will deliver as a motor when running with the same drop below synchronism. If, when motoring, full output requires 2 per cent slip, then, when generating, full output will be obtained at 2 per cent above synchronous speed.

Returning now to Fig. 4, if A and B are running without load and the motor at synchronous speed, and a load of 10,000 kw. is put on A's busbars, the speed of A will tend to drop 2 per cent with reference to B's speed. This means that the induction machine is running approximately 2 per cent above synchronism, since its speed is always fixed by B. It would therefore supply 1,000 kw. if B's speed remained constant. But a load of 1,000 kw. on B will cause its speed to drop 0·4 per cent, while the reduced load on A will mean less than 2 per cent drop, so that the set will not be running 2 per cent above synchronism, but something less than $2 - 0{\cdot}4 = 1{\cdot}6$ per cent. Thus it will deliver somewhat less than 800 kw. The exact distribution of load between the two stations may be calculated from the formulæ in Appendix 2, but it is easily approximated with a degree of accuracy quite sufficient for practical purposes.

From what has been said it will be obvious that the induction synchronous set is a much more flexible link for coupling up two power systems than is the synchronous set, and that it is possible to use a set of comparatively small capacity for linking up two large systems; for by making the slip fairly large it becomes almost impossible seriously to overload the set: also it requires a large variation in speeds to give a considerable transfer of energy from one system to the other. On the other hand, the induction machine always takes a wattless current and does not permit any adjustment of power factor on the system to which it is connected.

Advantages of Induction Motor-generator.

(1) It is a flexible link and permits a small set to be used between two large systems.
(2) It is easier to start and put into operation.
(3) By means of adjustable secondary resistance it is possible manually to control over a considerable range the amount of energy transmitted by the set, [illegible]

Disadvantages.

(1) A comparatively large difference in speed between the two systems is required in order that it may transfer its rated output from one to the other. This large difference in speed often limits the induction set to transmitting in one direction only.

(2) The induction machine requires a considerable lagging current, and no power-factor control is possible on this machine without introducing some form of phase advancer.

The great advantages which the synchronous set possesses, of permitting power-factor control and of transmitting energy in either direction without change in speed ratio between the two systems, make it desirable to use the synchronous set in preference to the induction set whenever possible. The great danger in its adoption is the possibility of overloading it and pulling it out of step. Of course it is possible to protect the machines from excessive overload by means of an overload circuit breaker; but, when the breaker opens, the machine must be synchronized again, and for a time there is no interconnecting link between the two systems.

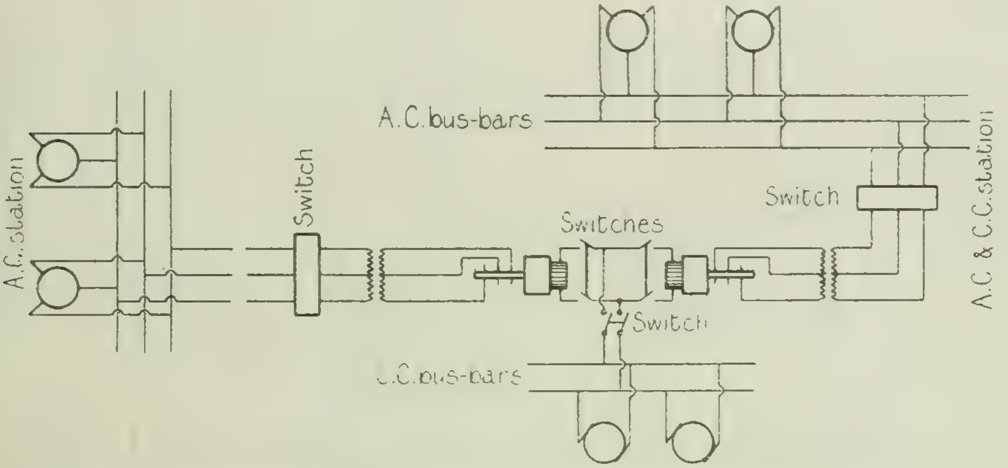


Fig. 5.—A method of interconnecting an a.c. system with a combined a.c. and c.c. system.

In general, a synchronous set should not be used unless its capacity is reasonably large with reference to the smaller of the two stations which it couples together—just what this relation should be depends upon a number of conditions. Where the stations are large and the changes in load comparatively small and not very sudden, it would probably be satisfactory to use a synchronous set having a rated capacity as low as 20 per cent of the capacity of the smaller station. Under less favourable conditions it might not be advisable to use a capacity less than 40 to 50 per cent of that of the smaller station. But where the synchronous set is as small as 20 per cent of the capacity of the smaller station, overload protection must be provided and occasional shut-downs may be expected.

With the induction set there is practically no limit as to size; for, no matter how small the set, the slip of the induction machine may be made large enough to prevent serious overloading; but it must be remembered that the greater the slip the greater is the variation in speed ratio required to obtain a given transfer in energy between the two systems.

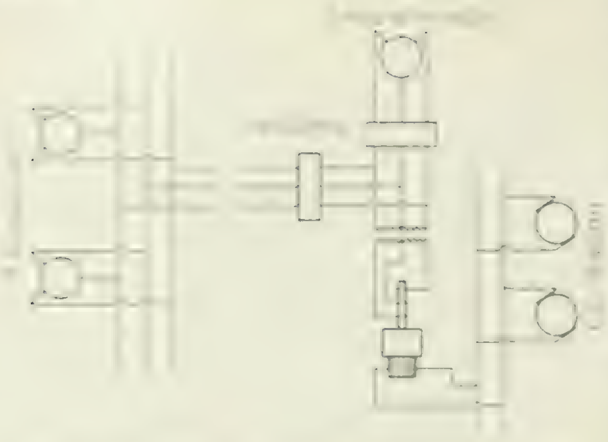
INTERCONNECTING THROUGH ROTARY CONVERTERS.

It was pointed out previously that under certain circumstances it might be desirable to interconnect two systems of different frequency by means of rotary converters. In general, this is only commercially feasible where continuous current is required in at least one of the stations. Fig. 5 shows two alternating-current stations of different frequency interconnected in this way. From the continuous-current side of the two rotary converters a connection is taken to the continuous-current busbars in one of the stations. With this arrangement it is possible to feed the continuous-current busbars from either or both alternating-current stations, or to supply alternating current from the continuous-current busbars to either or both stations; also it is possible to supply alternating current from either station to the other.

When rotary converters are used the transfer of energy from one station to the other does not depend upon the speed of the generators but is controlled by manipulating the voltage of the rotary converters, and means must be provided for accomplishing this result. This may be done by synchronous boosters or by transformer tappings, but, in general, reactance control will permit sufficient voltage variation to give the desired results.

In many large continuous-current stations extensions are made at present with turbo plant. Where the units are of considerable size it is customary to use a high-speed turbine and to gear it to a moderate-speed continuous-current generator, or else to use a high-speed turbo-alternator and to convert to continuous current through a rotary converter. The latter arrangement offers a ready means of linking up with an alternating-current station should it ever be desired to do so.

[illegible]



[illegible]

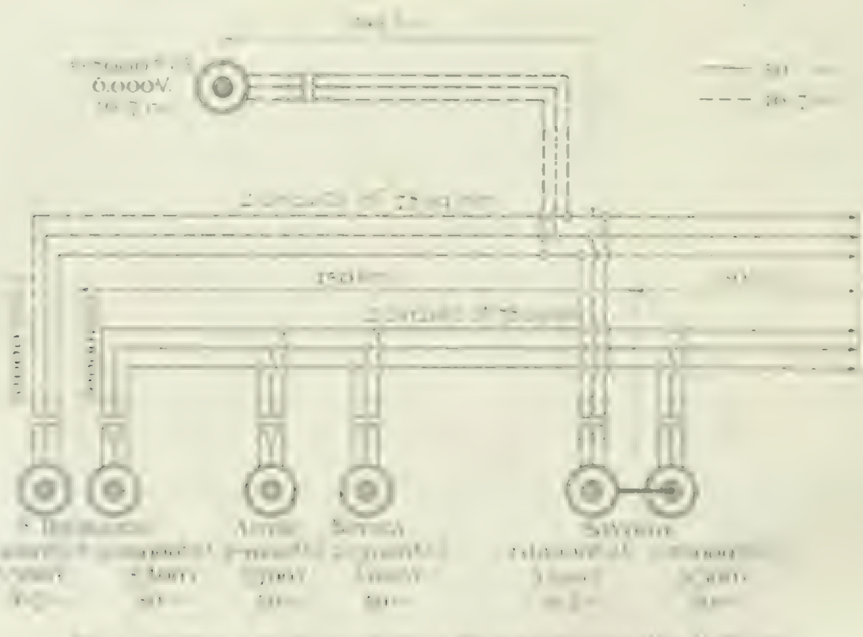
[illegible]

[illegible] systems of the same frequency in parallel, and on the Continent and in America many large transmission net-[illegible] motor-generators. One set has a 40-cycle induction motor [illegible] except that the heavy wattless currents taken by the induction motors limit the output of the stations and cables. A synchronous condenser is being installed which may work on either system. There are probably other cases with which the author is not familiar.

In France and in Italy there are some large systems of different frequencies connected through motor-generators, and the author is indebted to Mr. T. Prinetti of the Societa Elettrica Riviera di Ponente, Savona, Italy, for some particulars of a very interesting installation where a synchronous set is used for linking up two very large systems—one of 16⅔ periods and the other of 50 periods. The synchronous set consists of two 10,000-k.v.a. generators, one having 2 poles and giving a frequency of 16⅔ cycles, and the other 6 poles and giving a frequency of 50 periods. Fig. 7 shows a diagram of connections, from which the magnitude of the system may be seen. Mr. Prinetti says—

"Synchronizing is usually done by first synchronizing the turbine with the 50-period part of the plant, and afterwards with the 16·6-period part, the latter operation being very easy. Only from time to time is it necessary to telephone to other stations to adjust the speed.

"It was not necessary to apply any special device to the regulators of the water-wheels. The regulators are of [illegible] motor."



[illegible]

[illegible] of the [illegible] parallel, but [illegible]

[illegible]

In [illegible]

prohibitive price in Italy, the set does excellent service as a frequency changer.

SUMMARY.

(1) Polyphase systems of the same frequency may be connected together directly or through transformers, and operated in parallel without difficulty, but where each station supplies its own customers it is desirable to have some form of voltage regulator to permit independent control of the voltage of each station. If the stations are located in the neighbourhood of telephone or telegraph circuits, are connected solidly, and have earthed neutrals, provision must be made to prevent high-frequency currents flowing through earth between the stations.

(2) To interconnect a polyphase and a single-phase system of the same frequency a rotating machine of the phase-converter type or a motor-generator is required if the polyphase system is to be symmetrically loaded.

(3) Systems of different frequencies may be interconnected through frequency changers, sets consisting of two synchronous machines or of one synchronous and one induction machine. The synchronous set is usually the more desirable since it permits power-factor control and transmits energy in either direction without a change in the speed ratio between the two systems. It is, however, somewhat more difficult to operate, and to prevent danger from overloading it should have a fairly large capacity with reference to the smaller of the two stations which it interconnects. The induction set is much more flexible, and a small set can be used between two large systems, but it requires a considerable difference in speed ratio between the two systems for transmitting full load, and the induction machine takes wattless current from the system to which it is connected.

(4) In certain cases where continuous current is required the rotary converter may be used with advantage as an interconnector between two stations of different frequencies, or between an alternating and a continuous-current system.

In conclusion the author wishes to thank Mr. Prinetti for the interesting information he has supplied, Mr. J. W. Beauchamp for some useful suggestions, and Mr. H. Vickers for help in the preparation of the appendixes.

APPENDIX I.

THE EFFECT OF RESISTANCE AND REACTANCE UPON THE PARALLEL OPERATION OF ALTERNATING-CURRENT GENERATORS.

In a paper entitled "Current-limiting Reactances in Large Power Stations"* the effect on parallel operation of two alternators by inserting reactance between them was considered.

Where two stations are connected by a cable of considerable length the question of its resistance upon parallel operation must also be taken into account. The following treatment, though very incomplete, will serve to show the general effect of resistance upon the parallel operation of two generators or two generating stations.

In Fig. 8 let O A and O B represent the induced voltages of the two generators, assumed to be equal ;

α the angle of displacement ;

A B the resultant voltage, due to displacement ;

O C the direction of the cross current with reactance only in circuit ;

O D the direction of the cross current with reactance and ohmic resistance in circuit ;

ϕ the angle between O D and the voltage A B which produces it ;

R the resistance in the interconnecting circuit and in the generators ;

L ω the reactance in the interconnecting circuit and in the generators.

Then $$A B = 2 \, O A \sin (\alpha/2)$$

$$\text{Cross current} = \frac{2 \, O A \sin (\alpha/2)}{\sqrt{R^2 + L^2 \omega^2}}$$

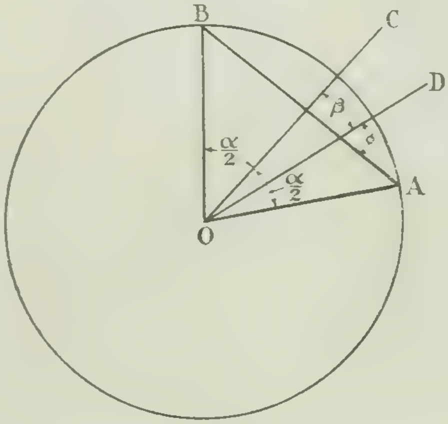


FIG. 8.

Total synchronizing power

$$= \frac{2 \, (O A)^2 \sin (\alpha/2)}{\sqrt{(R^2 + L^2 \omega^2)}} \left[\cos (\alpha/2 - \beta) + \cos (\alpha/2 + \beta)\right]$$

$$= 2 \, (O A^2/R) \sin (\alpha/2) \cos \phi \, [2 \cos (\alpha/2) \cos \beta]$$

But $$\beta = (\pi/2 - \phi).$$

Therefore total synchronizing power

$$= [2 \, (O A^2/R) \sin (\alpha/2) \cos (\alpha/2) \cos \phi \sin \phi] \, 2$$

$$= (O A^2/R) \sin \alpha \sin (2 \phi)$$

$$= (O A^2/R) \sin \alpha \cdot \frac{2 L \omega}{\sqrt{R^2 + L^2 \omega^2}} \cdot \frac{R}{\sqrt{R^2 + L^2 \omega^2}}$$

$$= 2 \, (O A)^2 \sin \alpha \, \frac{L \omega}{R^2 + L^2 \omega^2}$$

From these equations the following is apparent :—

(1) The synchronizing torque has a maximum value when $\alpha = 90°$. This, then, is the critical angle of displacement, as any further displacement will cause the machine to drop out of step.

(2) For any value of α the synchronizing torque is a maximum when $R = 0$.

(3) Without reactance there can be no synchronizing torque.

(4) For any value of R the synchronizing torque is a

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* *Journal I.E.E.*, 1914, vol. 52, p. 520.

[illegible] = 25 [illegible]

[illegible] When R [illegible] its effect on [illegible] frequency [illegible]. Thus, if R = [illegible] per cent [illegible] the synchronising torque is decreased only about 6 per cent. If R is increased to [illegible] per cent. the synchronising torque is decreased only [illegible] per cent.

The conclusions are, that, for any value of resistance [illegible] neglected.

APPENDIX 2

[illegible] LOADS IN INDUCTION [illegible] FREQUENCY CHANGER

Let a, b, and c represent the rated outputs of A, B, and C [illegible] (Fig. 4).

p_a, p_b represent the drop in speed (as a fraction of drop when supplying full load) for A and B.

p_c represent the slip of C (as a fraction of full-load slip).

L represent external load on B's busbars.

Assume first that A and B have the same drop in speed when delivering full load, and that this drop in speed equals the slip on C for full load.

Then, neglecting losses,

$$L = b\,p_b + a\,p_a \quad . \quad . \quad . \quad (1)$$

$$\text{and } c\,(p_b - p_a) = a\,p_a, \text{ or } c\,p_b = p_a\,(a + c) \quad . \quad . \quad . \quad (2)$$

From these equations the loads on A, B, and C may be calculated.

Assume a = 10,000 kw., b = 5,000 kw., c = 1,000 kw., and L = 5,000 kw. From (1) we have

$$5{,}000 = 5{,}000\,p_b + 10{,}000\,p_a \text{ ; and from (2)}$$

$$1{,}000\,p_b = p_a\,(10{,}000 + 1{,}000), \text{ from which is obtained}$$

$$p_a = 0{\cdot}0769 \qquad a\,p_a = 769 \text{ kw.} = \text{load on C.}$$

$$p_b = 0{\cdot}846 \qquad b\,p_b = 4230 \text{ kw.} = \text{load on B.}$$

If A and B have different speed regulations and C has a slip different from the speed drop of A and B, the same formula may be used by assuming the regulation of one station (B for example) as a standard, and increasing or decreasing the ratings of A and C in proportion, as their slip is less or greater than that of B.

For example, assume the speed regulation of B to be 3 % [illegible] A [illegible] 2 % [illegible] slip of C to be 4 %.

Then the load will be distributed as though the speed drops were all equal, and as though the rating of A were 10,000 × (3/2) = 15,000 kw. and that of C were 1,000 × (3/4) = 750 kw. Therefore assume

$$a = 15{,}000, \quad b = 5{,}000, \quad c = 750.$$

$$\text{From (1)} \qquad 5{,}000 = 5{,}000\,p_b + 15{,}000\,p_a.$$

$$\text{From (2)} \qquad 750\,p_b = p_a\,(15{,}000 + 750).$$

From which is obtained

$$p_a = 0{\cdot}0416 \text{ ; } 15{,}000 \times 0{\cdot}0416 = 625 \text{ kw.} = \text{load on C.}$$

$$p_b = 0{\cdot}875 \text{ ; } 5{,}000 \times 0{\cdot}875 = 4375 \text{ kw.} = \text{load on B.}$$

If there is a load on the busbars of both stations, then the station which would have the smaller drop in speed for the load connected to its busbars should be taken, and the load on the other station determined for the same drop of speed. The difference between the actual load on the busbars and the calculated load is that which must be distributed between the two stations, and the load on the frequency changer may be calculated according to the methods given above.

For example, take the conditions assumed in the last example, except that there is a load of 5,000 kw. on A's busbars as well as 5,000 kw. on B's busbars.

Now 5,000 kw. on A gives a speed drop of 1 per cent, and a drop of 1 per cent in speed gives a load of 1,666 kw. on B. Therefore, the load which must be divided between the two stations is 5,000 − 1,666 = 3,333 kw.

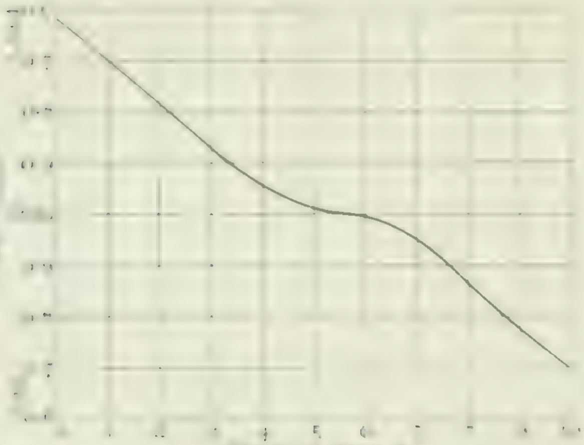
All of the above examples assume a straight-line speed curve, and the same no-load speed on both stations.

DISCUSSION BEFORE THE INSTITUTION, 23 NOVEMBER, 1916.

Mr. W. B. WOODHOUSE: I cannot help feeling, after reading the paper, that the author has given the impression that this is simply a problem of running generators in parallel, and that it does not matter whether they are in the same station or not. That is not the case. The problem is quite different—primarily because it introduces the question of transmission. The author might have emphasized much more the really vital point in this problem, namely, the question of controlling the power factor. The practical problem is the parallel operation of stations which are situated some distance apart, usually beyond the economical limit of their present distribution voltage. The justification for interconnection is that both systems get the benefit of the added security given by the [illegible] to the [illegible] at will. The problem is almost entirely one of transmission, and the governing conditions are voltage and power-factor regulation. Hunting, surges, [illegible] considered, but these deserve a paper to themselves. The case of interchange between two systems of different frequency, whilst presenting several very interesting technical points, is likely to be of decreasing importance, because a difference of frequency between two stations in the same area implies that one is non-standard, and therefore, as development takes place, the transfer of load will be all in one direction, the system with non-standard frequency being eventually either displaced or supplied as an ordinary consumer. The condition of most general interest is therefore the interconnection of two or more stations working at the same frequency, and it will simplify matters in considering this if I take the author's first example where he considers two systems, each with a normal load of 5,000 kw. and with provision for an interchange of 5,000 kw. A necessary condition of the problem is that the consumers' voltage on both systems is to be kept constant. Assume that it is desired to transmit from Station B to Station A a load of 5,000 kw. and of a power factor of

Mr. Woodho

r. oodhouse. 0·75 lagging, and that the impedance voltage of the interconnector is equivalent to 10 per cent of the line voltage. If Station B possesses no means of regulating the station pressure, and transmission is by means of a main of negligible reactance, the result will be that the voltage of B's consumers will drop 10 per cent. This is obviously not permissible, so that Station B must raise its voltage to the normal, which will produce a result dependent entirely on the nature of the transmission line; if the interconnector is without appreciable reactance the flow of energy will cease; that particular case can be left over for the moment; if the interconnector possesses reactance we have the interesting condition that power will only be transmitted from Station A to Station B in exchange for idle current from B to A. That is to say, Station B which is calling for power will have to supply (1) idle current for the load generated at B, (2) idle current for the load supplied by A, and (3) idle current for the regulation of the transmission line. Putting this into figures, on the assumption that the reactance and resistance of the transmission line are equal, Station B will require steam power to supply 5,000 kw., and alternator capacity to supply the following wattless k.v.a.: (1) for the load generated by B, 4,450 k.v.a.; (2) for that supplied by A, 4,450 k.v.a.; (3) for transmisson-line regulation, 5,000 k.v.a., so that Station B is in the unhappy position in this extreme case of requiring a turbine capacity of 5,000 kw. and an alternator capacity of very nearly 14,000 kw. That is equivalent to a power factor on the generators at the receiving Station B of about 0·33. Incidentally, Station A would benefit by being relieved of 9,450 wattless k.v.a. How are we going to get over these difficulties? The author has told us of several ways. The first, obviously, is the reduction of the percentage voltage-drop in the transmission line, which can be done either by putting more copper into the line or by increasing the transmission voltage. I think that is a very important matter to be considered at present. In view of the proposals for interconnecting existing systems at their present voltages, and the very interesting report that has emanated from Manchester, the effect of increasing the size of mains is of interest. There is of course a limit to the improvement effected by increasing the amount of copper, as it only deals with resistance drop and not at all with the inefficiency of transmitting wattless k.v.a. from one centre to another. Furthermore, if interconnection is by means of cables, the use of regulating transformers, which the author has described, or synchronous boosters, or the introduction of reactance becomes essential. The increase of the transmission voltage is another matter, and a consideration of this question is recommended to those who anticipate making considerable use of existing 6,000-volt mains for linking up. Money may easily be wasted if the transmission voltage is not sufficiently considered beforehand. One would be interested to hear the author's views as to the use of synchronous boosters. In conjunction with synchronous condensers they may form an advantageous alternative to regulating transformers. The use of regulating transformers for small powers is of course quite general, but it presents certain practical disadvantages if frequent changes of load are to be met. For large powers there seem to be disadvantages. For example, going back to the author's case of transmitting 5,000 kw. from one station to another over Mr. Woodhouse. a line with a pressure drop of 10 per cent, we can get over that 10 per cent by putting in a booster transformer at the supplying end, raising the voltage 10 per cent. That means we get the power to Station B at the right voltage, but it involves transmission at a low power factor; the energy lost in transmission will be 62 per cent greater than if the load were transmitted at unity power factor. Furthermore, unless the transformer is automatic, the interchange of idle current on large variations of load, such as occur regularly in power supply, may be unsatisfactory, and it does not by itself seem to be the most efficient way of dealing with the matter. There is another point with regard to the use of regulating transformers on existing systems. Most of the mains proposed to be used for interconnecters are tapped at various points. There are substations at various points of the mains and they are used to supply power all the way. It is obvious if that is the case, that we shall have to limit the amount of boosting that can be applied at any one point and that we shall probably require a transformer at each end. At the same time there are quite obviously cases where a regulating transformer is valuable. The third method, and the one that seems most likely to be generally adopted, is the use of synchronous condensers, which present much greater advantages as a means of regulation because they not only deal with pressure variation but with variation of power factor, and therefore one can control not only pressure but transmission losses. It is important to remember that if the voltages at the two ends of a transmission line are adjusted to be constant and equal at any load, they will remain so at all loads and the power factor will also be constant. Again, of course, we must consider capital cost. To transmit from one station to the other, we shall want at the receiving end a synchronous condenser, which is a somewhat substantial additional cost to that of interconnecting mains. If each station is going to depend on the other, we shall want a synchronous condenser at both ends unless we compromise and put one machine in the middle of the line. Running these machines also involves a certain amount of loss, their efficiency at full load is good, but at light loads the losses have to be reckoned with; the running arrangements must therefore be studied carefully. As an offset it must be remembered that the use of synchronous condensers will reduce the k.v.a. loading on the generators, thus not only enabling smaller generators to be used for a given kw. output, but reducing the stresses on them in the case of faults. Also, the synchronous condenser helps to balance unequally loaded phases. Nowadays I think all the power systems are meeting the difficulty of a decreasing power factor. There are a great many pieces of apparatus on the system which tend to reduce the power factor, and where in the old days we were content to rate an alternator for a power factor of about 0·85, nowadays we have to go down to 0·70. There is obviously a limit to that, and it is much cheaper in certain cases to put that additional alternator capacity into a synchronous condenser, build the alternator for a high power factor, and let the synchronous condenser deal with the idle current. In Yorkshire we are meeting with a considerable development of electric furnaces. Many of them are single-phase. Some which profess to give a balanced load unfortunately do not manage to do it, and so we have [illegible] g. So far as voltage regulation is [illegible], will probably be quite sufficient for [illegible] tic load in the future. The power-distribution [illegible] tations will be something of the order of 60,000 [illegible] cularly to be borne in mind, [illegible] ere is a tendency to think that all one has to do [illegible] le increase of efficiency. That is not so. As to [illegible] factor, I do not think it is sufficiently well realized what a very close connection there is between power factor and pressure drop in a transmission line. The use of automatic pressure regulators for power-factor control seems to be but little appreciated, yet it presents no practical difficulty, as will be seen if we draw the [illegible] hip between power factor and pressure drop in an [illegible] A). For all practical purposes it is a [illegible] wer factor. In practice [illegible] put the automatic pressure controller [illegible] ators or on the synchronous converters, [illegible] maintain constant voltage at their stations [illegible] As a case in point, on the Yorkshire system [illegible] er continuously. They are con- [illegible] nchronous machine to deal [illegible] sly the interchange of power [illegible] luce transmission losses. With [illegible] it is possible to arrange for [illegible]



[illegible] for constant kw. transmitted.

[illegible] a motor when required. That is the kind of thing that can be done in existing stations, but if we are going to deal with the practical problem of the future, running say 10 stations together, each station controlled by an independent authority, we are immediately met with the difficulty of dealing with changes of load. One cannot telephone to the 10 stations and arrange just what is to be done to meet an emergency; and practically, unless we can get a system which will regulate itself, this joint working cannot be carried out. The problem can be reduced to something quite simple, that is, automatic pressure regulation at each station, or some control point, and the load dealt with by each station regulated by the actual amount of steam available. They would do as we do with our smaller station in Yorkshire; if the steam pressure is rising they take more load. It is quite easy and automatic. I believe that is the method of the future. The whole problem, as it appears to me, is not so much a matter of the turbines—I think that [illegible] power factor and pressure regulation. One may paraphrase an old proverb and say: "Look after the power factor and the pressures will look after themselves." Mr. Woodhouse.

Mr. G. W. PARTRIDGE: Knowing the author's long experience of this subject I am rather disappointed in his paper. I thought that he would have told us a little more than he has done about the different apparatus used. The question of good parallel running depends first on the prime mover itself. It is very difficult to say what type of prime mover will be adopted in the future. It may be a steam turbine, a gas turbine, or a gas engine; but whatever the system may be, the parallel running of the prime movers should be made as easy as possible. The supply pressure can be easily adjusted, as it is simply a matter of static transformers at the generating stations or at the substations. From my practical experience I see no real difficulty in using on underground cables pressures up to 50,000 volts; in fact I have already seen underground systems running at 60,000 volts. There is, I know, a great deal to be said about the design of the cable used for this purpose, but to a certain extent it will depend in the future on the frequency of the supply. In planning any large extensions for the future, the frequency is the most important point of all. It is a matter which has to be settled once for all, and after it is once settled it cannot be changed. One has to take into consideration, in settling this point, the long lengths of trunk mains in circuit, the large size of units, and many other considerations. It seems to me that it might be advisable to adopt a low frequency for this purpose—in all probability lower than 50. The advantages of low frequency will be as follows: First, there will un- [illegible] systems coming out of step when any violent fluctuations take place. Another advantage will be that the regulation of the system will be much better. The next point is capacity current, which when long systems of trunk mains [illegible] frequency. In certain cases which I know of, it is impossible to run one generator alone on a large system owing to the great rise in pressure which would take place if the charging current of the system were equal to the short-circuit current of the generator, in which case the pressure Mr. Partridge.

would rise to hundreds of thousands of volts. The rises in pressure on extra-high-pressure systems would also be less if the frequency were low, and the actual switching of large circuits is also much easier on the low frequency than on the high, owing to the current remaining longer at the zero point. It is also well known that low-frequency alternators run much better in parallel than high-frequency alternators, and as I have said before, the possible prime movers in the future have to be carefully taken into consideration. The size of the interconnector cables referred to by the author is a matter of great importance and it is essential that there should be plenty of copper between the generating stations in order to ensure good parallel running, and more especially that there should be no chance of the two stations coming out of step when violent fluctuations take place. I think an induction regulator would be preferable for the voltage regulator referred to on page 62. I do not see how the reversing switch D can be opened on the primary side of the transformer when it is on load. I suppose the load would be reduced to zero before the switch was opened or reversed. In any case I much prefer the induction regulator. Regarding the question of earthed neutrals, mentioned on page 64, and the high-frequency current, we had this trouble many years ago when running in parallel with the Greenwich power station, and in practice one of the generating stations switched the earth off the neutral as soon as the station was connected in parallel. Special apparatus was designed which automatically reconnected the neutral to earth at the generating station in case it was accidentally disconnected from the circuit. I notice that the author on page 64 refers to the use of transformers for an earthing system. We make use of this particular system and find it works satisfactorily. The author suggests that use should be made of devices limiting the earth current to a negligible value. I think this would be impracticable because it is essential that the earth resistance should be low enough to allow sufficient current to flow through it to open the largest feeder on the system. I am particularly disappointed that the author does not say more about the phase converter. It is of considerable importance, more especially as I think in the future there will be many electrical furnaces used, and also a certain number of single-phase generating stations and railways, where it is important that all forms of supply should be taken from the standard three-phase system. With regard to the two types of frequency changers referred to by the author, I think where large systems are concerned the induction motor-generator is preferable to the synchronous motor-generator; as it is less liable to damage and less liable to fall out of step. At the present moment I am using an induction motor-generator having a capacity of 1,500 kw. to interconnect two systems of supply, namely, the three-phase 25-cycle 7,000-volt system to a single-phase 85-cycle 10,000-volt system. There is about 20,000 kw. capacity on one side, that is to say on the three-phase side, and about 10,000 kw. on the single-phase side. Now this motor-generator has been running satisfactorily for over six years and has never once come out of step, in spite of several very heavy short-circuits and several very heavy disturbances which have taken place on one system or the other. I went so far as to connect this motor-generator to one of the three-phase generators which was supplying single-phase current to the Brighton Railway. We had here a three-phase generator with an unbalanced three-phase load, and this motor-generator was connected in parallel with the 85-cycle generators and ran perfectly. The only drawback was that we could see the effect of each train start on the electric lighting system in the West End of London, so we had to disconnect it; otherwise it ran perfectly from an engineering point of view. The synchronizing of these motor-generators is a very important question. It is easy to synchronize the first machine, but the difficulty arises in synchronizing the second induction motor-generator, as the slip of the loaded machine is different from that of the in-coming machine, thereby making it necessary to synchronize through a special resistance; the ordinary starting resistance would not be suitable for the purpose. I think the synchronous phase changer would only be satisfactory with small systems of supply, because in running on large systems it would be liable to damage from the mechanical strains unless the machines were very expensively built. In any case it would be advisable for the synchronous machines to be provided with a heavy damping winding. These machines would also require a special synchronizing apparatus for synchronizing the second machine, due to the magnetic lag of the armature.

Mr. A. M. TAYLOR: I believe it will be found that reactances are very necessary in the coupling together of systems of any magnitude, even though they be of the same frequency and voltage. This is largely on account of the limitations found in all switchgear. It may be taken as fairly certain that with the most modern form of generating machinery, and with the most powerful switches in existence, it is undesirable to link together more than 30,000 kw. of machinery at 5,000 volts on one busbar, and where large power stations are near together any coupling together of two such stations, even if each may be of only 20,000 kw. capacity, would bring an unsafe amount of plant on to one system unless reactances be employed. In one large American system that I know of, several large power stations are thus connected together, with reactances in every case, except where the length of the interconnecting cable or overhead circuit makes this unnecessary. The synchronizing of large power stations is increasingly difficult as the stations become larger, owing to the difficulty of getting them into synchronism before paralleling, and it is conceivable that under certain conditions time may be of the greatest moment and might spell the difference between safety and disaster. I understand also that with induction motor-generators there is considerable difficulty in getting the speed adjustment, there being no load on the induction motor. It may be of interest if I say a few words about the possibility of paralleling stations through static frequency changers. I have now made tests on a 30-kw. 5,000-volt set, and have got to a stage at which I would be quite prepared to design frequency changers of at least 300-kw. capacity. The problems that occur in their manufacture are entirely those with which transformer builders are well accustomed to grapple; and I suggest that a "bank" of, say, 10 such frequency changers, representing a total of 3,000 kw., would be just as well able, if treated as a bank, to be suddenly switched in in the form of a big unit, as if they were built in one machine. The only loss would be a slight loss in efficiency and cheapness of construction, but

Mr. [illegible] [illegible] "back" would probably be [illegible] this would not much matter. Moreover, [illegible] be necessary to [illegible] nearly so closely [illegible] frequency changers and probably an error of 60° lag or lead, or even of 90°, would not be attended with serious trouble. For this reason it might be [illegible] static transformers, where a 6,000- or 9,000-kw. set would be necessary with rotating frequency changers. Another point about the static frequency changer is that short-circuits can take place with impunity on either side of the system. Within certain limits the apparatus will be reversible, possibly to the extent of its capacity. If, however, more than a certain amount of energy were passed through from the high-frequency side (75 cycles) to the low-[illegible] would be that triple-frequency energy would be superimposed on the low-frequency wave of E.M.F., deforming it in such a way as to make it more square topped, and to increase the root-mean-square value of the E.M.F., which would have the desired result of boosting up the overloaded system. The large lagging current, which is the worst feature of the static transformer, can be compensated by phase advancers at the station, as I understand is proposed for the induction motor-generator scheme. The static frequency changer takes a perfectly balanced current from the three mains, and delivers it to a single-phase system on the higher frequency. A three-phase supply can, moreover, be given if desired on the higher frequency without disturbing the balance. As regards regulation, 10 per cent can easily be given, and if necessary 5 per cent, although this involves greater outlay in material. By the use, however, of an induction, or a step-by-step, regulator the regulation can be brought down easily to 2 per cent or whatever may be desired. All the above remarks relate to step-up transformation from 25 periods to 75 (or from 16·6 to 50) periods, but I have also obtained entirely satisfactory experimental results with a step-up from 25 cycles to 50 cycles. This, however, I have not hitherto developed, owing to continuous-current excitation being required, but I see no difficulty whatever in designing frequency changers for this purpose which would be quite as satisfactory as those for the 25 to 75 (or 16·6 to 50) cycle step-up, and which would possess practically most of the same features. There would, of course, be no difficulty in a generating station in finding the small amount of continuous current required for excitation. I have also experimentally stepped down the frequency from 75 to 25 (or 50 to 16·6) periods, and probably the same could be done with stepping down from 50 to 25. If, however, the apparatus as already stated is found to be sufficiently reversible (so long as the 25-period supply does not entirely give in), there would seem to be no object in employing special transformers to act independently of [illegible] I would like to suggest that the simplicity of the static frequency changer, and the ease with which it can be switched into circuit under almost all conditions, and the fact that it requires practically no attention when once switched in, being capable of [illegible] apparatus; and, being easily capable of sub-division, the amount of apparatus left in at any time can be arranged to be more or less proportional to the plant in operation on the two systems, with corresponding economy.

Mr. Taylor.

Sir Charles

Sir CHARLES PARSONS: We are much indebted to the author for bringing this subject before us. At the present time many things, figuratively speaking, are in the melting-pot, and among them we are looking round to see how we can economize the resources of this country and incidentally distribute cheaper electricity. The trend of opinion at present is that the country should be covered with large distribution systems, and the difficulty is: what are we to do with our present stations, based, as they are, on various frequencies and pressures, and what is the cheapest and best course to adopt so as to secure an entirely satisfactory result with the minimum expenditure? I hope the author may tell us more of what is being done in America with regard to linking up, and give us some additional information on this subject. Some people think that we shall have to do a great deal of scrapping and that the uneconomical method of using frequency changers, which waste much more energy than pressure equalizers and boosters, should not be adopted. There is one point with regard to the future on which I should like to say a few words. Mr. Partridge has alluded to what is likely to be the prime mover of the future, and I should like to add further, the query—what will be the means of generating electricity in the future?—because several possible means have been suggested. For instance, we may possibly make electricity direct from coal without machinery. Then there is the possibility of perpetual motion—abstracting energy from the motion of the molecule, which would be quite a rational method if it could be accomplished. If we could only get machinery small enough to lay hold of the molecules as they vibrate, we should of course get energy for nothing. We could by this means abstract energy from the sea and reduce it in temperature and the energy would be available for work, and conversely this work would generate heat, and then we should get the cycle for nothing and without burning any fuel. However, there is no doubt that at present steam plant has no rival for large units, though it is not the most economical prime mover in small units, and its efficiency is getting very near to that of the internal combustion engine. On the other hand, the size of cylinder of the internal combustion engine is limited by what the metal will stand. Professor Hopkinson has shown that the heat radiated to the walls varies approximately as the square root of the dimensions, and its duration in a large engine is longer than in a small engine. Consequently the cyclic temperature rise and fall of the surface of the metal is much greater in the large cylinder than in the small cylinder, and a point is reached beyond which it is unsafe to increase the size of the cylinder, so that to construct a large engine means a multiplicity of cylinders. This makes the engine costly and also complicated for large units.

Mr. Bra

Mr. H. BRAZIL: I wish to say a few words on the frequency-changing apparatus used for transforming energy from one system to another, and perhaps my experience with the running of similar plant may be of interest. The author suggests three types of apparatus, namely, the synchronous motor-generator, the induction motor-generator, and the rotary converter. If the interchange of load is considerable, the question of efficiency will have to be carefully looked into, but of course efficiency is not everything in these cases, continuity of supply being equally important. What one desires to know is what will happen when a large interchange of load takes place. I have for some time been running substations with rotary converters, synchronous motor-generators, induction motor-generators, and Diesel engines, and it is interesting to see how the different types of apparatus deal with a suddenly increased load. The rotary converter will try to take the whole of the load that comes on the station, and also try to drive all the other motor-generators as well. The synchronous motor-generator will take a very considerable overload, and will keep in step, although the speed may be varying up and down quite audibly. The induction motor-generator will take the load quite well and will not drop out, unless it is very excessive. The Diesel engine, however, refuses to take any more load, and if one tries to make it do so by increasing the field, it will steadily decrease its speed until it is probably taking less load than before. Comparing the synchronous and induction motor-generators, I am in favour of the synchronous type, as it has a higher efficiency and is able to transmit energy both ways under all conditions, a matter of very great importance. It is true, as the author states, that an induction motor-generator will transmit energy both ways, but he does not make it clear that this is only possible when there is synchronous plant running on the system to which it is desired to give supply. This is a matter of some importance, as there should be many occasions when one desires to run one station only, and either station must be in a position to run. Coming now to the question of earthed neutrals, the author gives us four ways of getting over this difficulty; the first is, that one station only may be earthed, arrangements being made so that when the interconnector is opened the unearthed system will automatically be earthed. I do not like this arrangement because it involves some apparatus which is liable to go wrong, and the trouble that occurs on a system which normally is running with an earthed neutral, when the neutral point is disconnected, is very serious. I have known cases where the number of breakdowns on transforming plant due to the neutral being disconnected became quite serious. The second method is to run an insulated earth cable from the generating station of one system to that of the other, both systems having a common earthed point. This is a very good arrangement, but as the two generating stations are almost certainly a long distance apart, it would involve a very large expenditure, and I am afraid the cost would be prohibitive. The third method, as I understand it, is the insertion of transformers in the interconnecting line, so that the busbars of the two systems are not directly connected, and each can have its own neutral point earthed without there being any interchange of current through the earth. Putting transformers in the interconnecting line simply to do away with the earthed neutral trouble does not seem quite worth while, unless there are other advantages to be gained by inserting these transformers. The fourth method is to place reactances or resistances in the earth connection, so as to reduce the earth current to a small value; this to my mind is the best arrangement. The difference in potential between the neutral point of one system and that of another, is not, I believe, high, that is to say 300 or 400 volts. Consequently if we have a resistance of 20 or 30 ohms in each system, that is to say a total resistance of 40 or 60 ohms between the neutral points, there will not be much current flowing.

Mr. A. P. TROTTER: The author read a paper four years ago* on earthed neutrals, in which he dealt with the subject frankly and without any bias. It was fully discussed, and I think 26 speakers were in favour, 7 opposed, and 4 were neutral at that date. The question now is, assuming neutral earthing, how is it to be done? The matter may be treated from three points of view. First, the supply engineer considers the triple-frequency circulating currents if there is earthing at more than one point. The Post Office has to be considered, because if we earth at more than one point, telephones are likely to be troubled. The third is safety. One of the main objects of earthing the neutral point is to trip the circuit breaker in case of a serious leak. In case an overhead wire comes down, the engineer is quite ready to shut down that line until the wire is repaired. Most engineers want to shut down their cables in the event of a leaky cable, and I think the higher the voltage the better it is, because it is the more likely to develop a short-circuit between phases. The highest pressure, so far, in this country is 30,000 volts. I saw it stated the other day that the great handicap of supply companies in this country is the limitation of voltage by the Board of Trade. You all know that there is no such limit.

If one station only need be earthed—and I have not heard any reasons why it should not be so—that ought to be sufficient to open the circuit breaker, or the balanced protective device. If that is so, no insulated cable is wanted; I should be sorry to think it was necessary to have one. The current which is required to trip the protective device is so small that an armouring of the cable would do if necessary. It seems impracticable to limit the earth currents by reactances or resistances. If we are going to limit them from the point of view of the Post Office, we may have to come down to some micro-milliamperes, which we cannot be bothered with. We want to have a current which will definitely, and without any doubt, trip the earth circuit breaker, or better still, a protective device.

(*Communicated*): The following table shows the fre-

Electrical Supply Undertakings.

Frequency	No. of Stations	Thousands of Kilowatts
25	10	93
40	20	158
50	161	760
60	9	17
83	5	35
100	15	45
33, 68, 75, 77, 80, 90, 93	10	11

Electrical Power Companies.

25	4	78
40	3	317
50	8	117
60	1	36

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[*] *Journal I.E.E.*, 1913, vol. 50, p. 150.

[illegible] frequencies to 25 and 50, except in the North-East Coast district. It seems undesirable that tees or substations [illegible]

Mr. W. M. Mordey: What we have heard to-night [illegible]s the difficulties in distribution which result [illegible] low power factor. Those difficulties are so great that I am always looking for some development of the static condenser method of correction. Some years ago I read a paper * on the subject, giving some results of tests, and pointing out, with a view to inducing manufacturers or station engineers to experiment, the great advantages such condensers should have as compared with synchronous condensers, as over-excited alternators are being called. In that paper I showed that the losses in static condensers were very much less than those in synchronous condensers, that the cost based on such information as was then available was very much less, that they had the very great advantage of being stationary, and that they had the further advantage of giving a distributed correction when used instead of a local correction. I have been [illegible]ted that such things have never come into prac[illegible] so far as I know. Perhaps the author will tell us [illegible] ever investigated that question carefully. If they have not, I suggest it as probably a fruitful subject for a practical experimental investigation.

Mr. E. T. Williams: I should like to add an expression [illegible] indebtedness to the author. The subject of his paper, [illegible] the clear way in which the [illegible] ings to be discussed. I propose to [illegible] we see that due to the lack of foresight in the past, a large [illegible] adopted, and particularly that a considerable number [illegible] at different frequencies. I consider that great [illegible] neers in this country for [illegible] they have recently taken up [illegible] ply, and I think that we must [illegible] this enthusiasm leading us in wrong [illegible] In thinking over this subject, I [illegible] try have been divided into districts, as [illegible] of the first things required in each [illegible] to be arrived at with reference to [illegible] that the interconnecting between stations shall not be done direct from one station to another, but through the trunk main for the district. It will then be for the engineers of the separate supply undertakings to decide whether to bring their systems into line with the district trunk system or to adopt one of the devices dealt with in the paper. Each engineer will have to ask himself, seeing that the future demand for electricity will be far greater than it is at present, whether he would not best be serving the interest of his undertaking by boldly facing the changing of his system to comply with the system of the district at the initial stage. This will not prevent him installing a limited amount of interconnecting plant for use during the transition period, but such a plant would be strictly limited in extent and the arrangements made would be of a temporary nature. I think it will be evident that if a number of stations are interconnected through a common network, some form of central control will be necessary. This control would probably more readily be attained if a trunk system of interconnection is adopted. The great advantage of a district trunk system would be that any new stations in future could feed directly on to this system. It will be evident for example that, considering the reform in the London district, interconnection if not carried out in a manner suitable for bulk supply later will involve considerable expense and yet be no nearer to the ultimate solution of the supply problem for the London district, namely, by bulk supply from three or four stations situated in economic positions outside the district. Further, it would be a very great advantage if it could be laid down at an early date what system of inter-district trunk mains will be used as interconnectors between the larger districts. If this were once settled, it might possibly influence the decisions of the local committees as to the system to be adopted for the district trunk mains. It might also influence the designers of new power stations in their wish to be in a position to supply current in bulk through either the district trunk mains or the inter-district trunk system. I have endeavoured to emphasize the need for looking at the whole position clearly and fully, in order that if capital is expended now or other action taken, we shall not have to regret in future what we now do. I suggest there is an opening for one or more papers similar to the author's, but dealing with mains and interconnecting switchgear. I should like to call attention to the desirability when installing new interconnecting mains of also laying a multicore telephone cable, as it is considered that the communications with the numbers of stations running in parallel will be important; thus it is desirable that the telephone system for this purpose shall belong to the electricity supply undertakers and be used solely for their purposes.

Mr. [illegible] a special importance at the present time when the [illegible] cussed. Two stations working at the same frequency, where the power factor is high, and particularly where the generators are turbine driven, can be worked together with ease. Difficulties arise when reciprocating plant is used and when the power factor is low. These, however, can be overcome. Different frequencies at once introduce further problems. There is not much difficulty in giving a [illegible]

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* [illegible]

asynchronous motor-generators which can be run in parallel with the small plant. This method is equally applicable when the supply is to be given from one large station to another large station. It is then usually desirable that the arrangement should be reversible; in fact, it is generally so desirable even when one of the stations is small. To enable this to be done, the only method I know of is to use a motor-generator consisting of two synchronous machines, as the author points out. The difficulties are then greatly enhanced. First, there is the difficulty of paralleling both sides; this is not insurmountable, but, to say the least, it is not very convenient. The forces necessary to keep the two systems in parallel must clearly be transmitted through the motor-generator shaft; the shaft must therefore be of sufficient size. A disturbance at either station might cause these forces to be large, and great trouble would then result. The arrangement can be used under certain special conditions, but I cannot believe that it is one that will come into common practice. I think that all these methods for linking up and giving bulk supplies with alternating systems at different frequencies must be of the nature of make-shifts, and that ultimately the frequency must be standardized. Doubtless this progress will take considerable time. It is remarkable that whereas the Board of Trade fixed rigid standards for variation of pressure, no restriction was made as to frequency. I know of one system where, for a time, a frequency of 60 was given part of the day and 100 frequency during the other part. The problem is one which I had to consider for the western area of the Metropolitan Electric Supply Company, where the supply is two-phase 60 cycles. It was desired to give a supply in bulk to the different undertakings in the area working at frequencies of 50, 40, 74, and 90, all single-phase, besides several continuous-current systems. It was consequently necessary to use in any event rotating machinery in the substations. At that date none of the undertakers were at all likely to change their frequency, and what they were likely to want was a bulk supply of a few hundred kilowatts delivered to them at their proper frequency and with machinery suitable for running in parallel with their own plant and preferably reversible so that the supply could be reciprocal. The only way of dealing with this particular problem—which was quite a special one—was to use continuous-current motors for driving the sub-generators, and it was in order to get over the paralleling difficulties and to provide a supply of electricity in a form in which it could be sold that as a pioneering system the Thury method was adopted, the other advantage being that, after capitalizing the losses due to the constant current, the total cost of the cable system, in this case necessarily high, was much less than with an alternating system. Since the date (1907) of my first paper on this system,* the problem has taken a different aspect. It is now, I think, generally recognized that wherever economically possible the frequency should be standardized and the system changed to three-phase. There are, however, many instances where the cost of making the change is prohibitive.

Mr. Collis.

Mr. A. G. Collis (*communicated*): I am rather disappointed in this paper. The many practical difficulties experienced are not referred to, and the omission of the essentials for successful operation suggests that the title of the paper could be improved. Generalities are indulged in, and the chief point I notice is the necessity for proper adjustment of "steam supply," referred to on page 61. The responsiveness of the throttle control of steam to the variable conditions of electricity supply is well known, and the cyclic variation of the mechanical side imposes electrical control other than that referred to in the paper. One of the problems of the paralleling of station groups for units of high power is the limitation of the necessary switchgear devices for their control, and it is owing to this that the development of such stations has been retarded. This is not mentioned in the paper, but a suggestion in the form of a step-by-step regulator is put forward as a cure for such evils. Has it been used successfully, seeing that it is hand-controlled and its application similar to the despised rheostat referred to in the paper? There are obvious difficulties with this gear, and as I assume from the diagram on page 62 that the secondary of the current transformer forms a closed circuit to the secondary of the potential transformer, the terminal pressure of both secondaries must be the same, and the current in the secondary of the current transformer must be so arranged that it can pass through the secondary of the potential transformer. This being so, and since great difficulties are met in constructing this apparatus economically, it would be most expensive and no advantage would result from its use. Also, each station, or group of stations, would have to be provided with one of these equipments; and if either one or the other system experienced a short-circuit, the whole equipment would naturally be burnt out. Seeing that the pressure across the secondary of the current transformer will be proportional to the current that is flowing, it would be necessary to have someone continually at the rheostat to deal with fluctuations in the load when maintaining a constant pressure, which would be of course quite impracticable. However, I shall be glad to have full technical particulars of this apparatus before passing my final criticism. Again, no reference is made to the protection or maintenance of supply. If an accident happens, say, to one unit what is to be done? I contend that the following is necessary: (1) The unit should be disconnected when current is in the forward direction and at 75 per cent of the short-circuit value. (2) It should open on reverse current irrespective of the pressure. (3) An internal short-circuit on phases going to earth should be immediately isolated. (4) It must be impossible to switch on a dead machine. Figs. 4, 5, 6, and 7 do not suggest themselves as ideal owing to the necessity of flexibility of sectionalizing, unless these are only key diagrams. With reference to page 63, earth neutrals involve more consideration than is provided for in the paper. The critical and contentious points connected with parallel operation appear to be omitted, evidently for some reason; also all reference to the k.v.a. rating of switches. These are, however, the vital points of such control of electrical energy.

Mr. Peck.

Mr. J. S. Peck (*in reply*): Mr. Woodhouse has laid great stress upon the difficulties of operating generating stations in parallel under certain conditions, and in my opinion he has very greatly over-estimated the difficulties. Whenever it is proposed to make any departure from standard practice there are never wanting those who can give innumerable

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* *Journal I.E.E.*, 1907, vol. 38, p. 471.

[illegible] weight were given to their arguments progress would never be made. If it were not for the fact that stations are running in parallel in almost every country in the world (including Great Britain) where electric distribution [illegible] have reached any great magnitude, there might [illegible] purpose in discussing the possibilities of operating [illegible] was an accomplished fact, I took the possibility for granted, and dealt with some of the precautions which would have to be taken for operating under the conditions existing in this country. If these precautions are taken, I see no reason why entirely satisfactory results should not be obtained. It was pointed out clearly in the paper that where independent voltage control is essential at each station, some form of voltage regulator would be required. Mr. Woodhouse ignores this, takes as an example two stations where independent voltage control is not possible, and proceeds to calculate the excessive wattless currents which might flow under these conditions. By the addition of a simple and comparatively inexpensive voltage regulator, such as is described in the paper, the conditions would be entirely changed and the wattless load could be divided between the stations in any desired proportion. Even without a voltage regulator the conditions would never be as bad as he has stated, for stations never operate at an absolute constant voltage, and a certain adjustment is always possible. Low power factor is certainly a disadvantage on any system, but, in general, it is cheaper to put extra capacity into the generator than to install apparatus for improving the power factor. The advantage of the synchronous condenser is that it can be so placed and regulated as to keep unity power factor on the transmission line, and a constant voltage at the end of the line. But this advantage obtains whether the stations are operated in parallel or not, and the fact that with interconnected stations the wattless current may be shifted from one station to the other as desired, makes the use of the synchronous condenser less necessary than where the stations are operated independently. With regard to higher voltages for the interconnecting line, this would probably be necessary where the stations are far apart, but in certain districts where the stations are close together a 6,000-volt interconnector will probably be quite satisfactory. It is really a question of line loss as compared with the cost of transformers and high-voltage cables. Mr. Woodhouse thinks that the question of linking up systems of different frequencies is likely to become of decreasing importance. This may be so eventually, but it is likely to be of great importance in the near future. Some of the largest stations in this country are generating at 25, 33, and 40 periods, and there appears no possibility of their changing to 50 periods, not only on account of the enormous cost involved in scrapping the generating plant, but [illegible] to the fact that much of the consumers' plant [illegible] the 50-period systems, and for these [illegible]

[illegible] ing frequency changers, and especially information with [illegible] quite fully in a paper which has been submitted to the Institution, I simply touched on these matters in my paper, and confined it almost entirely to the question of load distribution between stations in parallel. As to the question of low versus high frequency, there is no doubt that a low frequency is preferable from the transmission point of view, but the turbine builders have found it possible to build larger and larger machines to operate at 3,000 r.p.m., and as the maximum speed for a 25-period machine is 1,500 r.p.m., it would appear that the lower cost and lower steam consumption of the 50-period generating plant would make a frequency higher than 25 very desirable. With reference to the operation of the reversing switch shown in Fig. 1, the diagram is not quite complete, as the switch is arranged in practice so that it can be reversed only while the secondary of the series transformer is short-circuited. Mr Peck

I agree with Mr. Taylor in thinking that if we are to link up very large stations by means of short feeders containing little resistance or reactance, it will be advisable to install reactance coils in the interconnecting line, not only to safeguard the switching apparatus but to limit the extent of disturbances in the event of short-circuits. Mr. Taylor has given some interesting information regarding his static frequency changer, but I am doubtful if this type of apparatus can ever replace rotating machines when transformation on a large scale is required. It is often found that apparatus which is quite satisfactory on a small scale presents unexpected difficulties when it is attempted to reproduce it on a large one.

Sir Charles Parsons asks for information with regard to what is being done in America. The parallel operation of power stations is so common in America that it may be said to be almost standard practice. There are several strong financial corporations which will buy up all the electric supply companies in a certain area, bring the various stations up to date, operate them in parallel, and so effect great savings in the costs of operation and improvements in the quality of the service given.

Mr. Brazil gave some interesting information regarding his substation plant, and he pointed out what I omitted to state in my paper, that with the induction synchronous frequency changer it is impossible to regenerate if the synchronous plant connected to the induction machine is not operating. My suggestion of running an earth cable between two stations was made merely as a possibility, as obviously it would be too costly to consider unless the stations were very close together.

Mr. Trotter pointed out that an earth current as small as one micro-ampere would be sufficient to affect telephone circuits. This disposes of my suggestion of earthing through choke coils and resistances.

Mr. Williams very rightly emphasizes the necessity for viewing the whole problem of linking up in a broad way, and, in order to secure in any district that all stations should have the same standard frequency, he suggests attacking the problem boldly and changing over those stations which do not conform to the standards of the district. Where these stations are of small size, there seems no doubt that this is the proper course to follow, but where the stations of odd frequency are of large size, say from 10,000 to 20,000 kw., the cost of changing over at once would be very great, and I think the possibility of changing over gradually should be given very careful consideration. A gradual [illegible] all

Peck. new apparatus purchased, all new feeder circuits, etc., would have the standard frequency, phase, and voltage of the district, and gradually the non-standard apparatus would be replaced by standard apparatus. For a time, frequency changers would be required, and for this purpose the old generating apparatus should be used as far as possible, e.g. if it is desired to change a plant from 40 to 50 periods, any new generating plant would be for 50 periods, and each new set could be coupled through gears to one of the original 40-period generators. This would give a generating set which could be used to generate at either 40 or 50 periods, or both at the same time, or it could be used as a frequency changer with the turbine running idle for converting from 40 to 50 periods, or vice versa. Some confusion might occur from time to time in operating two systems of different frequency from the same station, but there seems no insurmountable difficulty in accomplishing this.

Mr. Highfield seems to anticipate great difficulties in the use of synchronous frequency changers. Since writing the paper, I have received a report from the Engineering Department of the American Westinghouse Company giving some very interesting information on this subject. They say:

"The capacities of the 25- and 60-cycle systems of the Lehigh Coal and Navigation Company are in the neighbourhood of 20,000 k.v.a., 60 cycles, and 40,000 k.v.a. 25 cycles. A single frequency-changer set of 8,000 k.v.a. is installed in the 25-cycle station at Hauto, Pa., and the 60-cycle station is located a dozen miles away.

"Probably the most extreme case of using a relatively small frequency-changer set to connect two systems together is that of the Commonwealth Edison Company at Chicago. This company has installed several 5,000-k.v.a. sets, only one of which may be in operation during certain times. In this case, the 25-cycle system has a capacity of several thousand k.v.a., and the 60-cycle system has a capacity of at least 100,000 k.v.a. They have had some trouble on account of the frequency-changer set falling out of step, but not enough to make it a serious matter.

Mr. Peck. "We have come to the conclusion that the relative size of the frequency-changer set and the smaller of the two systems is of importance only when speed fluctuations in one of the two systems becomes excessive in range or rapidity. No hard-and-fast rule can be laid down that the frequency sets should be of a certain size in relation to the size of the smaller system. Some years ago we established a rule that the frequency-changer sets should be able to carry a load equal to the total load on the smaller system without dropping out of step. Since our synchronous motors in general would carry 100 per cent overload without falling out of step, this meant that the rated capacity of the set should be at least one-half of the total load on the smaller system. We believe now that this rule was unnecessarily safe, and we do not hesitate to quote on much smaller sets (in relation to the size of the systems connected) where we know that the frequency control on the two systems is good."

Mr. Collis expresses great doubt as to whether a regulator of the type shown in Fig. 1 can operate successfully. Regulators of this type have been in successful operation for approximately 20 years, and it is the type in general use to-day where heavy currents or high voltages have to be dealt with. His criticisms show that he is unfamiliar with the theory of shunt and series transformers. I am unable to appreciate his reasons for thinking that a short-circuit on a system provided with one of these regulators would cause it to burn out, since it can be made quite as robust as any other apparatus in the station. Fig. 4 shows a regulator of precisely the same type which is in regular operation in the interconnector between two large stations in London. The paper does not deal with protective relays for generators, as protective relays do not concern parallel running per se, and this subject would require a paper in itself. I had thought it would be apparent to everyone that Figs. 4, 5, 6, and 7 were purely diagrammatic, but I will now state that they are line diagrams reduced to the simplest possible form, and no attempt has been made to show provisions for sectionalizing.

MANCHESTER LOCAL SECTION, 28 NOVEMBER, 1916.

dhouse. Mr. W. B. WOODHOUSE opened the discussion. The substance of his remarks will be found on page 70, in the discussion before the Institution.

ertson. Mr. J. A. ROBERTSON: As most of you already know, a Committee composed of 12 engineers has been considering for some months past the problem of linking up supply systems in Lancashire and Cheshire, and have come to the conclusion that a scheme is commercially feasible and that there are no serious technical difficulties to be overcome. In the scheme it is proposed to make use of the spare capacity of cables already laid. The stations to be linked up in this district range in capacity from 200 kw. to 80,000 kw., the larger number being stations of medium capacity with maximum loads between 3,000 and 10,000 kw. With one exception the alternating-current stations are of the same frequency. I think Mr. Woodhouse has exaggerated the difficulty of operating in parallel, and the case he selects for illustration is one which could hardly occur in practice. During the last two years I have been responsible for the operation of a station at Salford working daily in parallel with the Lancashire Electric Power Company's station at Radcliffe. Under normal conditions Salford takes a supply up to 3,000 kw. from Radcliffe, but we have also delivered energy up to 2,500 kw. back to Radcliffe. At Salford two 5,000-kw. turbo-alternators with governors of the throttle type are working in parallel with three turbo-alternators at Radcliffe, fitted with nozzle-type governors. The Salford alternators are of the compensated-field type; at Radcliffe the alternators are uncompensated. The normal power factor on the Salford station is about 98 per cent. The Radcliffe power factor is about 78 per cent. The conditions are therefore about as bad as they could be for parallel running, but we have been able nevertheless to run for two years with satisfactory results. The stations are situated $6\frac{1}{4}$ miles apart with 5 miles of overhead line and $1\frac{1}{4}$ miles of underground cable. If two stations are connected in parallel at the same voltage, and the governor at the receiving station adjusted to take the Mr. Robertson.

[illegible] power factor on the line of 62 per cent, and the line losses [illegible] sending stations until unity [illegible] cent decrease in volts at the receiving station will raise the line power factor from 62 per cent to 97 per cent, and the line losses are then practically the pressure drop due to the ohmic resistance of the line. If it is desired [illegible] regards increase and decrease of voltage have to be reversed. To summarize the conditions, we can deliver 3,000 kw. either way with a total variation in voltage of about 7½ per cent. In cases where a large lighting load is supplied from the alternating-current system, this variation might be considered too high, and in those cases it will be necessary to make provision for varying the voltage either by a line booster regulator or by transformer tappings. It has been suggested that surging may take place between two interconnected stations. During two years of parallel operation we have had only [illegible] the cause, but it may have been due either to a governor trouble at one end or to the use of voltage regulators on the exciter fields. In running two generators in parallel, with a voltage regulator on each exciter, it sometimes happens that surging takes place, and the same thing will occur when running stations in parallel, although in a lesser degree owing to the resistance of the line. I think that when large systems are connected together, double- [illegible] formers are objectionable from another point of view, [illegible] than another, it is possible in the event of a fault occurring on one phase of the higher voltage system, to set up a pressure to earth on the lower voltage systems in excess of the normal working voltage. Interconnecting [illegible] and where large supplies are to be exchanged, duplicate [illegible] on the route between the two stations they should be connected to one line, leaving the other clear. At the same time there is no essential objection to consumers being [illegible] to a linking-up cable if the load is not large in [illegible] it will be necessary to have [illegible] distribute the load, and there [illegible] between all the [illegible] any real technical difficulties it [illegible]

Mr. [illegible] [illegible] for electrical engineers in general on account of the many technical problems involved. I propose to confine my remarks to one or two points. In the first place, I should like to ask the author about the connection of the boosting transformer shown in Fig. 1. It seems to me that it would be better to put a transformer in each phase, for the connection as shown would lead to unbalanced load on the phases and tend to make the running of the machines unstable. The author has indicated a method of calculating the distribution of load on two stations connected by an induction motor-generator set. I have also derived formulæ for achieving the same object, and I think they are of sufficient interest to present in the discussion.

Mr. Vict

Let the two machines be referred to as A and C, and the motor-generator as B.

Let A = normal output of machine A,
B = normal output of motor-generator,
C = normal output of machine C,
[illegible]
p_2 = percentage regulation of motor-generator set,
p_3 = percentage regulation of C.

We will consider two cases, viz. (*a*) load on one side only, (*b*) load on two sides.

Case (*a*) : Let there be a load X on the network supplied by C, and let δX = load taken by generator C. Then $X(1-\delta)$ = load taken by the motor-generator set.

The percentage drop in speed of $C = \delta X p_3/C$. The [illegible] the motor-generator.

Therefore the percentage drop in speed of generator A

[illegible]

The percentage regulation or slip of the induction motor

[illegible]

and the output of the motor-generator

[illegible]

[illegible]

Case (*b*) : Load on both sides. Let a load X be thrown on the C side and a load Y on the A side. Let $\delta_1 X$ be the fraction of the load taken by the generator C. Then [illegible]

The actual percentage slip of the induction motor

[illegible]

ickers.

Also $$\frac{X(1-\delta_1)p_2}{B} = \frac{\delta_1 X p_3}{C} - \left\{Y + X\frac{(1-\delta_1)}{\eta}\right\}\frac{p_1}{A}.$$

From this equation

$$\delta_1 = \frac{X\left\{\frac{p_2}{B} + \frac{p_1}{\eta A}\right\} + \frac{Y p_1}{A}}{X\left\{\frac{p_2}{B} + \frac{p_1}{\eta A} + \frac{p_3}{C}\right\}}.$$

The load taken by generator $C = \delta_1 X$

$$= \frac{X\left(\frac{p_2}{B} + \frac{p_1}{\eta A}\right) + \frac{Y p_1}{A}}{\frac{p_2}{B} + \frac{p_1}{\eta A} + \frac{p_3}{C}}.$$

By putting $Y = 0$ in this equation, δ_1 reduces to

$$\frac{C p_2 \eta A + C B p_1}{B p_3 \eta A + C p_2 \eta A + C B p_1},$$

i.e. the expression for the fraction of the load taken by the motor-generator with load on one side only. The expressions seem long in comparison with the simple expressions given by the author, but they enable calculations to be made directly.

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Professor A. B. **Field**: This paper brings home to us once again the penalty demanded for our haphazard lines of electrical development. We have not only great varieties of voltage, frequency and types of plant to provide for, but also must contend with existing two-phase systems which will need to be linked up with three-phase ones until the former systems shall have become abolished. In the matter of meeting the exact frequency ratios we may sometimes have a little trouble; for instance, when 60 and 25 cycles are involved, the maximum speed of a set comprising two synchronous machines directly coupled together is 300 r.p.m. When the linking together of a two-phase and a three-phase system is in question, difficulties due to slight phase distortions easily arise unless greater care is taken than has been used in some cases in the past. A rather exaggerated case of such trouble comes to my mind; it occurred on a power system in the United States, in which two two-phase 2,200-volt plants had to be linked together. The distance separating the plants necessitated a transmission voltage in the neighbourhood of 25,000, and for the sake of the advantages of transmission, three-phase was used on the line: there was thus involved a two-phase to three-phase transformation at each end of the line, and the Scott connection was used for the purpose. In operation, it was found that at the receiving end the two-phase synchronous motors accepted the bulk of their power on one phase, leaving the other phase lightly loaded, and the unbalancing was enough to cause serious heating of the windings in the overloaded phase. Rotating the connections at the motor gave no improvement; even slightly raising the voltage (by taps on the transformer) on the unloaded phase failed to equalize the distribution of load. It had been supposed that conditions would be best if symmetry were maintained as much as possible, and to this end care had been taken to see that that transmission line which was connected to the teazer transformer at one end was also connected to the teazer transformer at the other end. As a matter of fact, it is best to avoid this arrangement; and further, for one direction of transmission, the improvement by shifting round the three connections between line and transformer at the receiving end in one direction is greater than if the connections are shifted round in the other direction, as shown in Figs. B, C, and D. It is easy to see how the leakage reactance of the transformers introduces a phase distortion in the case of the Scott transformer connection, and how the effect may be serious unless suitable precautions are taken in the design of the transformers. The diagrams and explanation below have been added to elucidate this point better; the two-phase side is referred to as the secondary, and the three-phase as the primary, each end of the line, in the following:—

Professor Field.

Consider the three-phase side of, say, the step-up pair of transformers; for simplicity assume the two-phase supply voltage to be undistorted, and the three-phase current to be symmetrical. The main and teazer transformers will generally be of similar design, except possibly for taps and connections. In the teazer primary we have the current all of one phase. In the main transformer, on the other hand, we have the current in the two halves of the primary differing in phase; in fact, these currents are displaced from the secondary current by 180° ± 30° respectively, as indicated in Fig. B; in this figure the full lines show the primary and the dotted the secondary currents. Each primary current may be considered as made up of a component in phase with the secondary, B E and E A, plus a component at right angles to the secondary, E O and O E. Were the two halves of the primary so well interwoven that the two components O E mutually counteracted one another magnetically, without leakage, then the reactance voltage for each half of the main transformer would correspond only to the components of current in phase with the secondary current. Actually this will not be so, and there will be, in addition to the chief reactive voltage, a further one for each half of the primary, corresponding to the component O E. This voltage will be in phase with the secondary current, and it is this supplementary effect which introduces the phase distortion. The actual figures denoting the relative primary conditions for the teazer and each half of the main transformer will be approximately as follows:—

	Teazer	Main
Current, total	I	I
Ditto in phase with secondary current	I	0·866 I
Ditto at right angles to secondary current	Zero	0·5 I
Primary turns involved in reactance voltage	0·866 T	0·5 T
Ampere turns involved in the chief component of reactance voltage	0·866 T I	0·866 T I
Ditto, in component of reactance voltage which is in phase with secondary current	Zero	0·25 T I
Reactance voltage, chief component	0·75 $T^2 I v_1$	0·433 $T^2 I v_1$
Ditto, component in phase with secondary current	Zero	0·125 $T^2 I v_2$

[illegible] woven, the ratio v_2/v_1 would be negligibly small, and the net primary reactance voltage would be at right angles to the phase of the secondary current in each of the three cases;

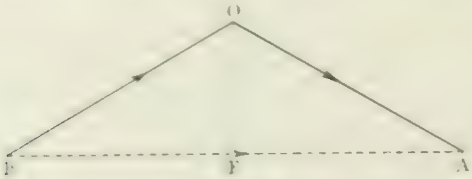

Fig. B.

the value of the reactance voltage for the teazer would be 1·73 times that of each of the other two, and this distribution would leave the three-phase voltage symmetrical on balanced loads of all power factors and with either direction of phase rotation. If the two primary circuits of the main transformer were obtained by merely tapping the mid-point of an ordinary single-phase winding, then v_2 would be much greater than v_1, and the resultant reactive voltages would be turned round more than 30° from their previous phase, that is beyond the point at which they would be at right angles to the primary currents (see Fig. C). The effect here described can be mitigated by interspersing the primary coils of one half of the main transformer with those of the other half, as well as with the secondary coils, or by using two secondaries in parallel (e.g. see the author's Fig. 3), or by a closed compensating winding, in an evident manner. Figs.

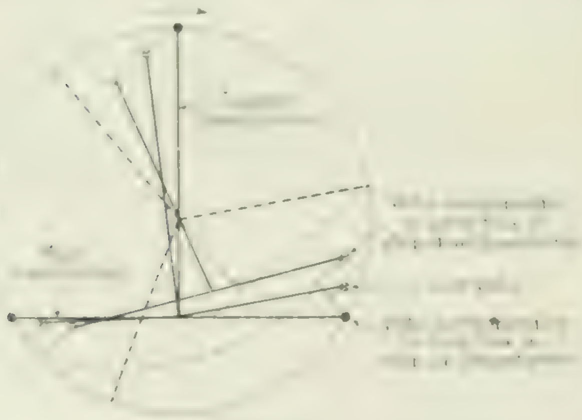

Fig. C.

[illegible] D indicate in a general way the distortion of phases [illegible] in the case discussed (taking $v_2 = 3 v_1$); for the sake of [illegible]licity, line-drop and I R drops are omitted, the [illegible]e currents are shown as though balanced and [illegible] and the two-phase supply voltage as though [illegible]

marked Δ); also the slight further improvement* effected by rotating these connections one point in the reverse direction instead (see the points marked O). In these diagrams the dotted straight lines indicate current- and

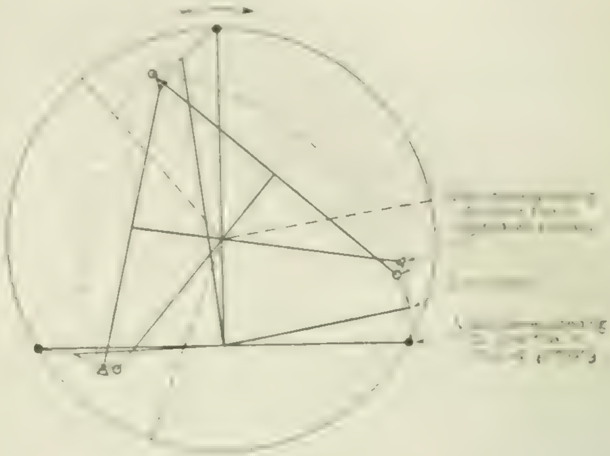

Fig. D.

the full ones voltage. The three-phase voltages are represented by vectors drawn from the centres of the diagrams to the points marked variously by circles, spots, triangles, etc.; these lines are omitted to avoid complicating the diagrams. Otherwise the figures are sufficiently self-explanatory.

Mr Juhlin

Mr. G. A. Juhlin: This paper is welcome because there appears to be need for a clear exposition of the parallel operation of power stations in parallel, especially in connection with the wattless load. It seems clear that the amount of wattless current required is determined by the load conditions of the systems, provided that the voltages at each end of the interconnector are adjusted to take care of the drop in the interconnector. The problem is very similar to that of two alternators running in parallel, one of which is provided with an automatic regulator. In such a case it is of course necessary to adjust the voltage on the other machine by hand, in order to prevent the first machine taking more than its share of the wattless load. The fact that the load of individual alternators running in parallel is adjusted by a change in speed, and not by field adjustment, would seem to require to be emphasized. In this connection I have in mind a case which came under my notice some years ago in an industrial station. The equipment consisted of some reciprocating sets, which could not be loaded to the capacity of the engines owing to the low power factor of the system. Subsequently a turbo-alternator was added, and it was then discovered that by increasing the excitation of this machine it was possible to increase the load on the reciprocating sets; and the result was that the load on the turbo-alternator was adjusted to the full-load amperes, regardless of the power factor and the temperature of the rotor. In connection with the arrangement shown in Fig. 5, some difficulties would arise if it should be desired to regulate the alternating voltage by means of reactance control, with one alternating-current station shut down. In such a case the frequency would

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[illegible]

uhlin.

vary if the regulation were done on the inverted rotary converter, or the continuous voltage would change with the alternating voltage if the direct-running converter should be used for the regulation.

ramp.

Dr. W. Cramp: This paper ought to be discussed by those engineers who are in charge of large schemes and who are interested in linking up, rather than by those dealing with smaller systems. But even for the latter it raises some very interesting questions. The author suggests that at the present time there is no trouble with parallel operation. That is overstating the fact. With turbine generating sets there is very little trouble, but in Lancashire schemes it will probably be necessary to parallel gas-engine sets with turbine and steam sets. Does the author think that this will cause no difficulty? Again, where more than two power stations are operating in parallel it is difficult to see how the division of load is to be accomplished with induction synchronous machines unless there is more than one linking machine between each pair of stations, or duplicate connections are arranged. As an instance, suppose three stations, A, B, and C, of which A is the largest, and B is larger than C. Suppose also that B is 10 miles from A and that C is 15 miles from B and 25 miles from A. Then if an induction synchronous set is installed between A and B it will naturally have its motor fed from A, and similarly the set between B and C will have its motor fed from B. If each linking set has a slip of 4 per cent at full load, the frequency of the systems A, B, and C may under the worst conditions be 50, 48, and 46 respectively. In many cases (as for instance the cotton industry) the difference between 50 and 48 would be serious, but in nearly every case the change from 50 to 46 would be prohibitive. Thus the use of induction synchronous machines is strictly limited. Again in even the simplest case what is the position as regards reversibility? If A is connected to the induction motor of the linking set it can obviously divert power to B; but should A break down, B is powerless to help. This, however, might be provided for by arranging the connections between A, B, and the linking set so that either station might feed the motor and be fed by the generator. This does not appear to be an expensive addition, and I should like to ask the author if it has been tried or even proposed. In Appendix I, Fig. 8 will call for explanations from many readers. There are two apparent difficulties. The first is that though under the circumstances which the diagram represents, one machine must be receiving power from the other, yet in the expression for the total synchronizing power, the power given by one machine is added to that received by the other. Or, in other words, the angle $\alpha/2$ while reckoned in opposite senses in the two cases is yet given the same sign. The physical explanation is that the synchronizing power must be defined as the rate of expenditure of that energy which tends to bring the machines into synchronism. Work done in accelerating the slower machine is just as effective in synchronizing as that done in retarding the faster machine; so that though the work done is, as regards the individual machines, of opposite sign; yet as regards synchronizing it is of the same sign. The other difficulty in Fig. 8 is that though the whole power given out by one machine must be received by the other, yet they are apparently of very different magnitudes, one being proportional to cos $(\alpha/2-\beta)$ and the other to cos $(\alpha/2+\beta)$. The physical explanation again is that, neglecting the power lost in the leads connecting one machine to the other, there is still a part of the energy in the system which in one of the two machines does not help towards synchronizing. In the faster machine—the generator—the armature resistance loss tends toward retardation; but in the slower machine this loss does not tend toward acceleration. This is not brought out in the diagram because for simplicity's sake the author has left it somewhat incomplete. To show the whole completely, either O A or O B should be drawn in the opposite sense and the potential difference at the terminals of either machine inserted, together with the impedance drop of each machine. Then the derivation of Fig. 8 is immediately apparent. When at the beginning of the paper the author refers to Appendix 1 as "treating the subject in a general way" I think he is a little optimistic. For his solution does not consider the effect of load upon the machines, nor take into account the different effect of the iron losses in the generating and motoring machines respectively. I proposed here to give a general diagram covering all these points, but I see that C. P. Steinmetz* has already treated the subject so thoroughly that there is no object in saying more.

Dr. Cramp.

With regard to Appendix 2, a curious difficulty arises if in the case suggested by the author we consider the conditions when C is fully loaded. L should then be 6,000; but if this be substituted in the author's equations, it will be found that C comes out as 1,080 instead of 1,000 kw. The reason is that Equation (2) is really only approximately correct. If S_a is the frequency of A when supplying the required load, and S the frequency of A and B at no load, then Equation (2) would be more nearly correct if written

$$C\,(p_b - p_a) = a\,p_2\,S_a/S.$$

In other words Equation (2) neglects the fact that the induction motor of C when supplied at frequency S_a will have a lower speed at full load than when supplied at frequency S. This correction spoils the simplicity of the author's equations, which are near enough for nearly every case in practice, and far more useful to the engineer than the more correct form. Since, however, the discrepancy may puzzle others I thought that the explanation would be welcome.

Mr. Frith

Mr. J. Frith: I should like to ask the author whether it is a suitable way of describing Fig. 8 in Appendix 1 to say that, as far as the alternating frequency goes, the vectors represent root-mean-square values, but as far as the phase swing is concerned the figure represents an instantaneous position of affairs.

Mr. Ellis.

Mr. A. G. Ellis: The paper emphasizes the important rôle which static transformers will play in the matter of linking up supply systems and in the solution of problems arising therefrom on systems of the same frequency. We are now at a stage where a static frequency converter would be a valuable asset, but there is at present no such commercial apparatus available. There exist static frequency converters for obtaining triple-frequency currents by means of a highly saturated "neutral" core of a three-phase transformer, carrying a winding in which a third-harmonic voltage of three times the primary

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* "Alternating Current Phenomena," 3rd edition, p. 315.

[illegible] of the low degree of [illegible] a small percentage of the supply voltage. The flexibility and adaptability of static transformers render them serviceable for voltage regulation, as noted in the paper, and also for phase conversion, especially in the case of the Scott connection for two-phase to three-phase conversion. Among the unfortunately far too numerous different systems in this country, there are still a number of two-phase systems, and, in some of these, Scott groups are already installed for [illegible] three-phase systems. I was interested in Professor Field's remarks about the out-of-balance of a three-phase transmission system stepped up from two-phase at the generating end and down again to two-phase at the receiving end. With proper disposition of the windings on the transformers, balance should be obtained on the secondary side when the primary side is balanced, and by suitable design and grouping of the phases, in general any balance trouble can be overcome. The Scott system possesses great flexibility for conversion from two-phase to three-phase or six-phase. Mr. Woodhouse mentioned the case of a system using delta-star connected transformers where parallel operation with star-star connected transformers was precluded on account of the secondary phase displacement of 30°. This does not deprecate the delta-star connection, as it is quite possible to bring the secondary voltage into phase by the choice of suitable transformer connections, it being of course well known that the star zig-zag connection will parallel with the delta-star.

Mr. H. A. [illegible]: The paper certainly provides a strong argument for the standardization of frequencies, since the main difficulties incidental to the parallel working of power stations appear to arise in connection with the operation of frequency changers. The author says that the frequency changers should be designed for abnormal conditions; but if they are large enough to deal with such conditions it is quite possible that one result will be an extremely poor overall efficiency; for presumably the load under abnormal conditions would be very much greater than the normal running load, and it therefore means either running a large machine at a comparatively low load or otherwise paralleling smaller machines, which apparently introduces other difficulties. These difficulties are not specifically mentioned, but the paper deals with the subject very completely, and by reading carefully between the lines it is evident from various little hints and [illegible]s that they have a very real existence. There is an extremely candid statement at the bottom of page 67 to the effect that "occasional shut-downs may be expected." [illegible] the earthing of the neutral points, the first [illegible] great extent the primary object for which the resistances have been inserted in the earth connections. With regard to the question of static conversion from single-phase or two-phase to three-phase, the various systems for converting from two-phase to three-phase or vice versa are quite sound, with the exception of the slight trouble referred to by Professor Field, but in the case of single-phase it is quite a different matter and, as the author states, can only be done at the expense of unbalancing the load on the separate phases. It is sometimes stated that this can be done, and no doubt it is possible to convert from three-phase to single-phase with an equal current on all three phases; but the power factor would be different on each of the three phases, and consequently the load would not be balanced. Obviously a polyphase supply can never be converted successfully to a single-phase one through the medium of static transformers, since one is a constant and the other a pulsating delivery of power.

An interesting feature in connection with the use of induction frequency changers is the comparatively large slip necessary to transfer an appreciable load from one system to the other. If there are two stations "A" and "B," one of which, say A, has a reputation for maintaining a constant frequency, whereas B is perhaps not quite so particular, and if these stations are linked through a converter requiring a 2 per cent slip, then between the conditions when A is supplying power to B, and the conditions when B is supplying power to A, there will be a total variation of 4 per cent in the frequency of the B station. Such a large variation would I am afraid hardly suit the Lancashire textile industry. The vector diagram on page 69 and the conclusions derived from it are particularly interesting. A few years ago when reactances were first introduced in America they were advocated as the panacea for nearly all the troubles incidental to electricity supply, including the difficulty of paralleling power stations through long tie lines owing to the comparatively large amount of resistance in the circuit. The added reactance was intended to produce the lag in the circulating current between the separate machines or stations necessary to give the synchronizing power components. The author's conclusion on page 70, that "for any value of resistance likely to be found in practice its effect may be neglected," does not therefore seem to be quite in agreement with the American experience, and it would be interesting to know whether this is due to the fact that in England, at any rate, the distances between power stations are short compared with the distances in America; and also possibly because the permissible current density in underground cables is less than for overhead lines. The vector diagram is a little difficult to comprehend; but calculations based on a modified diagram lead to the same result as the one given in the paper. Possibly my method of drawing it would be more in accordance with Dr. Cramp's criticisms. The line joining A and B is rather puzzling and I think the diagram would be more easily [illegible] vector about the point O, with the vector representing the synchronizing current lagging behind it. The two perpendiculars drawn from the end of the current vector to one E.M.F. vector and to the other one produced backwards, would give the retarding and accelerating synchronizing power components. These of course are not equal but

Ratcliff. differ by an amount equal to the losses in the machines and connecting cables. The E.M.F. or induced voltage vectors would naturally then be drawn rather less than 180° apart. Taking the example in the last paragraph on page 70 and completing the calculation, gives apparently a load of 416 kw. on the converter. The capacity of station A is 10,000 kw., of station B 5,000 kw., and of the converter 1,000 kw., and therefore, although B is nearly fully loaded and A only half loaded, the converter is only able to utilize 416 kw. of its 1,000-kw. capacity; which is less than 10 per cent of the load on B, and less than 5 per cent of A's capacity. This does not appear to be a very economical working condition when the comparatively high cost of the converter is considered.

Hornby. Mr. B. S. HORNBY (*communicated*): The author has not directly referred to the drop in pressure in the interconnecting cables. This will not be negligible if the works are a considerable distance apart. The boosting arrangement he refers to can of course be used to compensate for this, but it is questionable if it should be fixed in one of the generating stations. No doubt in some cases existing mains supplying consumers will be extended for interconnection purposes, and in this event the best position for the pressure-regulating plants appears to be at the place where the authorities make the interconnection. Switchgear will be required at this point, and some no doubt will insist on main transformers being used, "even if the pressure, etc., of each system are the same," in order to keep the systems electrically separated and to comply with the Board of Trade requirements regarding earthed neutral points. If this position can be used by more than two authorities so much the better, in order to save attendance and iron losses, if common transforming plant with separate windings for each system is used. When main transformers are used in the interconnecting circuit, other methods for regulating the pressure can be adopted. Fig. E shows a regulating switch similar in principle to the well-known battery regulator. This has given satisfaction on high-tension transformers of moderate size, and if inserted in the star point where usually there will only be a small potential to earth, and immersed in oil, should prove satisfactory on larger ones. Fig. F shows another known method which prevents the attendant short-circuiting the transformer windings between the tappings; this, of course, is only applicable when the adjustment can be made before the interchange of power is required. Mr. Hornby.

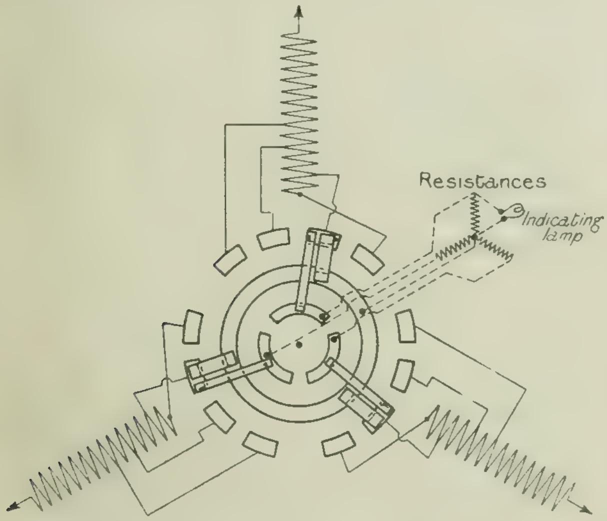

FIG. E.—Regulating switch connected to tappings from star-connected three-phase transformer.

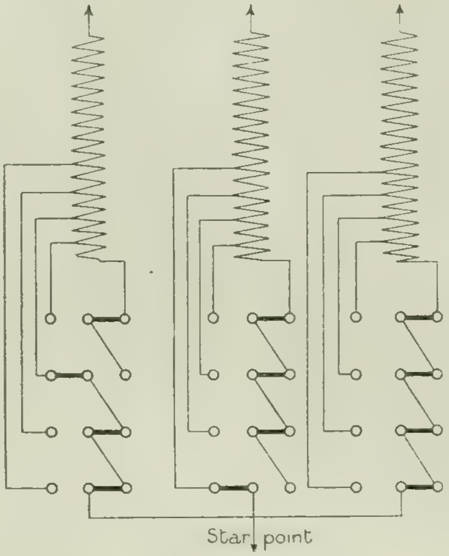

FIG. F.

Mr. Peck. Mr. J. S. PECK (*in reply*): Mr. Robertson has given some very interesting information with reference to the parallel operation of the Salford station with that of the Lancashire Electric Power Company, and it is very interesting to see that no serious difficulties have been encountered. I hope that Mr. Robertson will give us full particulars of the connecting feeders between the two stations, and also it would be useful if he would give in more detail the results of the tests which he has actually taken.

With regard to Mr. Vickers' remarks, I do not think that the arrangement shown in Fig. 1 of the paper will give unbalanced voltages except to a very small degree due to a slight difference in the value of the impedance introduced by the regulating transformers into the different phases; but, as was pointed out by another speaker, this method of boosting on two phases only, shifts the position of the neutral point of the system, so that two stations connected through a feeder, having a booster of this type, could not both be earthed. The only advantage of this regulator is that it is cheaper than the three-phase regulator. I am obliged to Mr. Vickers for working out the complete equations for calculating the load on an induction frequency changer.

Professor Field gives some interesting information relating to transformers, connected according to the "Scott" method, for changing from two-phase to three-phase. The unbalancing in voltage which might occur was one of the difficulties foreseen by Mr. Scott when first bringing out his invention, and great care was always taken to interconnect the windings on the three-phase side of the main transformer so that there would be a minimum

Mr. Peck. reactance between the two halves of the winding. Hun[illegible]ners were built in this manner, and no [illegible]. If the two halves of the winding are not properly interconnected, the unbalancing may be very serious.

With reference to Dr. Cramp's remarks on parallel running, it is generally safe to assume that if the different [illegible]rs in a station run well in parallel with each other, [illegible] run in parallel with those in another station. As [illegible]ty of connecting several stations by means of [illegible]chronous sets, it is true that a difference in speed ratio is required in order to make the set take its full load, but the value of 4 per cent taken for the slip is altogether too high. In general, it will not exceed 1 to 1½ per cent on a machine of, say, 1,000 kw. capacity, but even with this small slip the difference in speed ratio may be very objectionable under certain conditions. Another objection to the induction synchronous set pointed out by [illegible] regenerate if the synchronous plant, to which it is usually connected, is shut down. The suggestion that this might be overcome by arranging the set so that the connections of the two machines may be interchanged, with reference to the generating stations, is hardly feasible for the following reason: A motor-generator set is only utilized for interconnecting where the stations have different frequencies. Therefore, the induction machine must be wound for a different frequency from that of the synchronous machine, and it is obvious that under these [illegible] it would not be possible to interchange their [illegible]

Mr. Frith is correct in assuming that the vectors of Fig. 8 represent in magnitude root-mean-square values, but their positions do not represent instantaneous values in the usual sense, as a certain angular displacement may be constant for an indefinite period.

Mr. Ratcliff suggests that a frequency changer will have to work at low load most of the time, and will therefore be an inefficient, as well as an expensive, piece of apparatus. The extent to which it can be loaded will depend on the rate at which the loads fluctuate on the generating stations. If load changes are gradual, the set can be worked at approximately full load most of the time, for even at full load there is approximately 100 per cent margin before it will pull out of step. If, however, the loads fluctuate too rapidly to permit any adjustments of the governors, then the frequency changer would have to be made of larger size or more lightly loaded. When considering the question of the effect of resistance in the feeder upon parallel operation, it should be remembered that the reactance of the generators themselves must be taken into account. On the other hand, if the interconnecting feeder is of very small capacity in comparison with that of the generating stations, its ohmic value may have a very appreciable effect on synchronizing power.

Mr. Hornby shows two types of regulators connected directly to transformer tappings. The face-plate type with preventive resistance should be quite satisfactory, if the currents are not too large or the voltage per step too high. The switch-type regulator, as shown, involves the opening of the circuit for each change in voltage, but by increasing the number of switches it is possible to introduce a preventive resistance, and regulators of this type have proved very satisfactory.

BIRMINGHAM LOCAL SECTION, 6 DECEMBER, 1916.

Mr. Chattock. MR. R. A. CHATTOCK: The great advantages of linking up electric supply stations are the more economical running of the generating plant, the reduced quantity of spare plant that would be necessary, and the greater reliability of the supply. The paper deals with several difficult problems that will arise in connection with such linking up. I am very interested in the experiment that the author describes, by which the Salford undertaking has [illegible]ng, and it is very satisfactory to know that a load [illegible] kw. can be transferred in either direction with a [illegible] of only 3 per cent in the voltage at either end. It would be interesting to know what is the capacity of the mains and transformers used in this experiment, as [illegible] a low potential difference it would seem that the [illegible]t have been considerably in [illegible]ities, the induction [illegible] efficient in operation [illegible] circuit. This is a very important point because the power [illegible]ns has a tendency to fall [illegible] very serious one in the case of small undertakings. The method of interconnecting through rotary converters appears to be the most flexible, though the cost of the apparatus required may be prohibitive if large interchanges of energy are required. With this system a storage battery can be connected between the two continuous-current ends of the rotary converters, and in this way can be used as an emergency standby to either system until further generating plant can be got away to assist. The voltage regulation can be most easily provided by this system and the power factor on the circuit can be adjusted so that all the copper in the cables can be utilized for the transmission of energy. The synchronous motor-generator is rather too rigid in operation to be satisfactory, although with careful handling this objection is not very serious. It is obvious that when two synchronous machines coupled together are synchronized between two systems very great care must be exercised so as to get the final connection exactly in phase; if it is slightly out, when the switch is closed, the machine will have to pull the whole load on one system into step with itself and this will cause a very heavy strain upon the windings of the machine. I consider that high-voltage transmission, even over comparatively short distances, should be used for linking up. It is highly desirable to insert transformers to separate the systems, and sufficient reactance can be inserted in these tock.

to control undue surges of current under breakdown conditions. By inserting such a break in the metallic connection between systems the difficulty of double-earthing disappears. High-voltage transmission would also lead to economy in the cost of the copper that it would be necessary to lay for such links.

Taylor.

Mr. A. M. Taylor: With underground three-phase cables, the reactance drop is practically negligible and the resistance drop (at 5,000 volts) amounts to about 1¼ per cent per mile at 1,000 amperes per square inch. Now, the "instantaneous" reactance of most alternators is of the order of 8 to 10 per cent; so that up to 8 miles the diminution of the synchronizing component of the current in the mains need not trouble us; and, if we are to include the reactances of the alternators at *both* ends of the transmission line, we may go up to 16 miles before the reactive and resistive components approach one another in value, and parallel running consequently becomes less stable. With voltages higher than 5,000, these distances will be proportionately increased. With reference to the parallel working of two or more separate stations, I notice that the author seems to suggest the use of automatic voltage regulators at all the stations. I believe that in the larger stations it will be found desirable to have non-automatic regulators, especially in those stations in which the busbars are subdivided by means of reactances. Under such circumstances it will very likely be found undesirable to have any fixed voltage control. The power factor of the currents passing through the different reactances will be what has to be watched. A Tirrill, or other automatic voltage regulator, does not display discrimination in an emergency; all it does is to keep the voltage constant. It also may, and occasionally does, get out of order itself; and the more nearly it approaches perfection and is therefore relied on for all emergencies, the more chance is there of a serious accident through its sudden failure. If two stations, A and B, are running in parallel and something goes wrong with, say, B's Tirrill regulator, causing the exciters to fail to excite, then the alternators of that station will throw off the lagging wattless component of the load which they have been carrying, and this will consequently have to be borne by the alternators of station A. If these —a very common occurrence with earlier sets—cannot maintain the standard voltage in spite of this very heavy lagging component, the Tirrill regulator at station A will not be satisfied, and tremendous magnetizing currents will be sent from station A to station B, causing the generators at A to be still further reduced in voltage, because they now supply not only the whole lagging component of the load proper, but also a lagging current equivalent to the leading current taken by B's generators. The two stations will thus be rapidly thrown out of step, with possible disastrous results, as the action is a cumulative one. If stations A and B are really big stations, there is no need for an automatic regulator at either, on account of the slow variations in the load, and I cannot help feeling that hand regulation is safer, as it introduces intelligence in operation, and there are other things to consider than voltage. It does not appear, at first sight, as though the failure of the governor gear of either station would lead to such serious trouble as the failure of the Tirrill regulator. A question that crops up incidentally is the advisability, or otherwise, of using "failing field" relays on the generators. In the contingency mentioned above, those on station B would all operate, under conditions tending to cause a rise in voltage of certain parts of the circuit to nearly double the normal existing to earth, with possible breakdown of current transformers, etc.

Mr. Taylor.

Mr. Orsettich.

Mr. R. Orsettich: The calculations of the size of the cable for linking up two supply stations can be considerably modified if the purpose of the linking is ascertained and put under one of the two headings: (*a*) the linking up is for the purpose of supplying the peak load in either station whenever these peak loads happen to take place at different times; (*b*) the linking up is for the purpose of supplying the whole of the requirements of the given station during times of light load, such as night loads, Sunday load, and so on. The static boosters proposed have one objectionable feature, namely, the switch and open contacts to adjust the tappings require to supply a given voltage. Movable contacts for carrying large currents have not proved satisfactory in starters and similar switchgear and are a certain weakness of the proposed arrangement. It is suggested that either an induction regulator or some type of synchronous booster should be adopted instead. I have carried out two installations of linking stations of different periodicities, in one case linking a 40-cycle station with a 50-cycle one, and in another case a 50-cycle station with an 87-cycle one. The supply, however, was entirely through the link whenever the link was operated and this made matters considerably easier. The machines used were synchronous machines in one case, and to adjust the phasing-in a rocking stator was used for one of the units. In the other case an induction motor-generator was used and then the periodicity of supply fed through the link was lowered to suit the slip of the induction motor. The author mentions that it is good practice in the States to link large supply centres by means of a motor-generator of an output of 10 per cent of the total of either station, but the main peculiarity of this system is that it is not apparent for what purpose the linkage with such a small link should be adopted. Continuous-current linkage by means of a double set of rotary converters was adopted in Birmingham to link up the Aston station working on 50 cycles with the Birmingham supply working on 25 cycles, the output of the rotary system in this case being equal to half the output of the station at Aston. The objection to the proposed method of earthing stations linked together at one point appears to be the impossibility of quickly removing the earth connection should any point of the system break down to earth. Two of the difficulties which appear to exist in any linked-up system do not seem to have been fully discussed in the paper, viz. the necessity of providing very large switchgear at the ends of the links so as to break the maximum short-circuit likely to happen at any point in the system, and also the probability of having to deal with heavy surges on an extended system with long feeders and with the load concentrated at the end of these feeders, especially when synchronous machines were used.

Dr. Kapp.

Dr. G. Kapp: The well-known law that maximum control is obtained if inductance and resistance are equal, does not mean that one should increase resistance to bring it up to equality with inductance, but only the reverse. If the resistance is high then an increase of inductance up to equality with this high resistance will strengthen the

Kapp. [illegible] the resistance is small the stronger control can only be obtained by a decrease of inductance. The author has formulated the law correctly in paragraph (4) of Appendix 1. I am, however, not able to agree to his definition of "total synchronizing power." [illegible] the sum of the excess power given out by the leading machine and the deficiency of power in the lagging machine. I think synchronizing power should be defined separately for each machine, and if this is done we find for the leading machine

$$P = \frac{E^2 A}{R^2 + L^2\omega^2}\left(L\omega\sin\alpha + 2R\sin^2\tfrac{1}{2}\alpha\right)$$

and for the lagging machine a similar expression, but with the second term in the bracket negative. Since *a* can only be a small angle the second term is negligible, and we thus get for the true synchronizing power exactly one-half of the value given in the paper. The effect of resistance is, as the author points out, not very important, but it is not quite so small as stated* in (5). With a resistance equal to 50 per cent of the inductance the reduction of synchronizing power is as 4 to 5, or 20 per cent, and not 12 per cent as stated. It is convenient to give the synchronizing power in kw. for one electrical degree phase-difference between the two machines. If the open-circuit voltage (star value) is given in kilovolts (kv) and resistance and reactance refer to star values also, the synchronizing power of a three-phase machine is

$$\text{kw.} = 26\,\frac{1}{R + \omega L}\,\text{kV}^2.$$

It should be noted that ω L is not constant, but depends on the load. It has two components: the one is the true inductance, or rather the average inductance which may

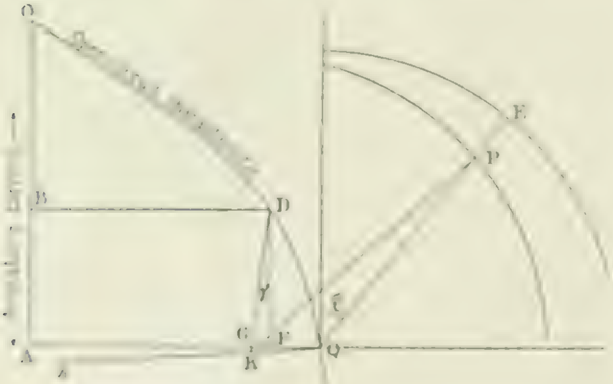

Fig. G.

be found by passing a current through the armature, measuring the E.M.F. required when the relative position [illegible] Let, in Fig. G, O C be the open-circuit E.M.F. [illegible]

an ampere scale such that A B represents back ampere-turns, i.e. in a three-phase machine 2·1 × conductors per phase per pole × effective amperes; then O B is the exciting force which would be acting if the armature current were lagging by 90°. In this case Q F would be the reduction in E.M.F. due to back turns. Let λ be the inductance of the armature measured as before described (or calculated in any of the well-known ways from slot and head leakage), then ω λ I is the drop due to true inductance. Draw a line from D at such a slope that tan γ = ω λ; then F G is the true inductive drop and Q G is the total inductive drop for a current lagging by 90°. For any other lag the drop is Q G × sine of lag. A circle drawn from G will then be the locus for the external E.M.F. vector for the particular current I = A B, and if we wish to take the resistance also into account we draw the circle not from G, but from K on the resistance line Q *k*. The drop from no load to a load of I amperes is E P. By repeating the construction for various values of armature current we can with very little labour prepare a curve such as Fig. H connecting current and inductance. To the current

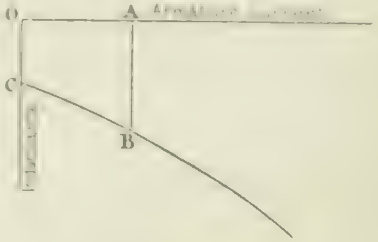

Fig. H.

O A corresponds the inductance A B, and to zero current the inductance O C. It will be seen that the inductance increases with increasing load, which means a reduction in controlling power with increasing load. When dealing with the induction motor and synchronous generator the author points out that by making the slip fairly large it is almost impossible to overload the link between two stations; also that a smaller set may be used than if both machines are synchronous. The two disadvantages mentioned are a large difference in speed and bad power factor. Now both of these do not seem to me to be very serious, whilst the flexibility of the system and the freedom from dangerous overloading are very important advantages. A 1,000-kw. induction motor can easily be made for a slip of 1 per cent, and by using a phase advancer of the vibratory type the slip will be increased at full load to something like 1½ or 2 per cent. The phase advancer itself would be quite a small and inexpensive apparatus, so that the only objection remaining is that of a slip of at the most ± 2 per cent. This does not seem a very serious matter, considering that most motors in practical use have a larger difference than 2 per cent between light and full load.

Dr. [illegible] It is probable that [illegible] the linking-up of existing generating stations is the most immediate and practical step that the electric supply industry [illegible] rard.

this linking up. There is, however, one aspect of the question which he has not dealt with and on which I think the success of such linking-up proposals will in a large measure depend. I refer to the control gear. It is now recognized that control gears, for example oil switches, must be chosen having regard to the maximum value of the short-circuit current which can occur in the places where the switches are situated. Even with existing supply stations it is very doubtful whether the breaking capacity of the oil switches which are available has kept pace with the growth of the generating plant. It is not unusual to find supply stations equipped with switchgears which, owing to the continual addition of generating machinery, have become insufficient in size for their duty. The result of this is that on the occasion of short-circuits the switches fail, with consequent interruption of the supply. We can therefore conceive two stations the switchgear of which is adequate having regard to the individual totals of plant installed. The effect of linking them up, however, by diminishing the inherent reactance of the system greatly increases the short-circuit current and renders the whole of the switchgear inadequate. As has already been indicated, this trouble can be partially guarded against by the introduction of reactance in the interconnectors. There is, however, to my mind, no doubt that if we are to go in for large schemes of linking-up it will soon be found that the types of control gear which we have available are inadequate, and that this will prove a limiting feature. The largest types of oil switches hitherto made have probably been developed in America. These switches, however, have been mainly used for overhead lines having comparatively large reactance values, and it does not necessarily follow that the same switches would give satisfaction when used with underground cables, as would be largely the case with us. It seems to me that this question of control gear for very big supply systems is one which should be given special attention by the Institution. There is undoubtedly a large amount of information that could be made available if an organization existed which could gather it together and put it into a form available for the industry in general. On several occasions in the last few months, I have heard indirectly when travelling about the country of certain troubles which have been experienced by supply companies on the lines indicated. No doubt the engineers concerned have profited considerably by the said experiences, but I think there is no doubt that it would make for progress if the details of the occurrences were available generally, so that the engineers of other undertakings could guard against a repetition. The American Institute has such an organization in the form of a standing High Tension Transmission Committee which is called upon to report periodically on the general progress of high-tension work, and the Swiss Society of Electrical Engineers also does the same kind of thing. I should therefore like to suggest that the Institution should take this matter up. I think no action of the Institution could be more helpful than this in the advance of British electrical engineering. The present haphazard method of leaving it to the individual manufacturers and supply companies and municipalities is very unsatisfactory, and a co-operative and co-ordinated effort such as I have suggested is what is required. Take as an example the question of oil switches. How large should an oil switch be which is called upon to break, say, 200,000 kw.? This would not be a large amount of power for a system having, say, 30,000 kw. of plant connected in parallel. I am almost certain that if the various manufacturers were asked to put forward a switch, very great variations would be found in their proposals. It may not be generally known that the Verband Deutscher Elektrotechniker has already issued a report upon this very question, but, as far as I am aware, nothing whatsoever has been done in this country. This is essentially a question of research. I am certain that both manufacturers and users would heartily welcome any information on this subject. I would suggest, therefore, that the Institution be asked to form a representative Committee for this purpose with instructions to report, say, every six months. It would also have to spend a good deal of money, as experiments would have to be organized, etc.; moreover, in order to make rapid progress it would be necessary to retain the services of a good engineer to act as secretary to the Committee. The Committee could issue a report every six months and would give reliable and unbiased information as regards all progress, experiences, and experiments made in the meantime. I have no doubt that if such an organization could be got to work, in a very few years the problems which are now a source of considerable anxiety to many supply companies' engineers would be solved and a great advance made in the reputation of British manufacturers of this class of apparatus. I should only like to add that, in view of recent announcements by the Government, I think it very likely that a grant of money for such a research might be obtained if proper representations were made.

Dr. Garrard

Mr. Jones.

Mr. C. JONES (*communicated*): The linking up of large power stations is certainly the right thing to do in order to economize, and especially the linking up of the large colliery power stations with municipal supplies, as the exhaust and mixed-pressure turbines are greatly used at large collieries; and this should tend to cheapen the cost of production, etc. One point in connection with power-supply work is the very low power factor that is obtained in a great many cases, but this is now being improved by the use of static condensers. My firm, the Cannock Chase Colliery Co., have installed three sets of 340, 400, and 600 mfd. capacity respectively, and these have been in use for over 12 months without giving the slightest trouble. The result of the introduction of these condensers was the shutting down of a 200-kw. set, the losses in cables being therefore reduced. There are other useful examples of synchronous motors in use at collieries, driving fans, compressors, etc., where mechanical work is obtained in the improvement of power factor, the number of kilovolt-amperes being reduced by their introduction and useful work performed in addition to the power-factor improvement.

Mr. Peck.

Mr. J. S. PECK (*in reply*): Mr. Chattock mentions the possibility of interconnecting through rotary converters and using a storage battery as an emergency standby. This is another of the possibilities of this method of linking up, but, as previously stated, I am of the opinion that this method, on account of the high cost of the apparatus, will be feasible only when continuous current is necessary for distribution purposes or for charging batteries.

With reference to Mr. Taylor's remarks re automatic [illegible] regulators, I did not intend to suggest that regula- [illegible] between the stations is not rapid it might be possible to do so. The troubles which he mentions as likely to result in case of the failure of the regulators are inherent in the regulator itself, and may cause trouble in a single station [illegible]

Mr. Orsettich refers to the practice in America of linking [illegible] changers having 10 per cent of the capacity of the smaller of the two stations. I do not suggest that this is standard practice, but it is quite possible to do so when the load fluctuations are small and not too rapid. In general, the larger the stations the smaller are the fluctuations in load, and it is of course the fluctuations and not the size of the stations which determine primarily the maximum load on the interconnecting link. As to the utility of so small a frequency changer, it seems quite possible that under certain conditions it might be of great advantage to shift [illegible] the other, as it might make it possible to run with less plant.

I am much obliged to Dr. Kapp for pointing out an error in the figures for the effect on synchronizing power due to resistance, and this has been corrected in the *Journal*. As to whether total synchronizing power should be taken as the sum of that on both machines, or simply that on one machine, is a matter of dispute, but is probably of little importance so long as it is clearly defined.

I am quite in sympathy with Dr. Garrard's suggestion that we should have standard rules for oil switches, corresponding somewhat to those of the Verband Deutscher Elektrotechniker, and the matter is now being carefully considered; but I think it would be a mistake to try, as the Germans have done, to specify dimensions, speed, amount of oil, etc., as these are matters which each manufacturer should decide for himself, and were they rigidly fixed there would be no room for progress. In general, manufacturers wish to be told what is required of apparatus, and resent being told how it is to be [illegible]

COLONIAL TELEGRAPHS AND TELEPHONES.

By R. W. WEIGHTMAN, Member.

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SYNOPSIS.

General.—Introductory. British Post Office practice. Appointment of engineers. Working staffs. Sources of supply.
Administration.—Small Crown Colonies. Large Crown Colonies. Telegraph Administration. Telephone Administration. Canada, Australia, New Zealand, South Africa. Amalgamation of Railway Telegraphs with Postal Telegraphs. Electric lighting in charge of telegraph engineers.
Engineering.—Overhead construction.
  Pole lines: Crown Colonies and South Africa, Canada, Australia, New Zealand.
  Pole fittings: Ditto.
  Line wire: Ditto.
  Farmers' lines on fences, Canada.
  Telegraph systems: Crown Colonies, South Africa, Canada, Australia, New Zealand.
  Telephone systems: Ditto.
  Lightning dischargers and protectors.

GENERAL.

Introductory.—When it was suggested to the author that he should write a paper on his own experience as a telegraph and telephone engineer he thought it desirable to cover the wider field of telegraph and telephone engineering throughout the Dominions and Colonies. The fact that such a paper had not previously been submitted to the Institution encouraged the idea, and the author's long experience in South Africa and his later experience with Messrs. Preece, Cardew, Snell, and Rider in dealing with the telegraph and telephone work of the Crown Colonies, South Africa, and New Zealand, appeared to warrant his undertaking this task. While he has aimed at dealing as fully as possible with what have appeared to him the more interesting features, the author has had to pass over very many matters of detail which he could not enter upon if the paper were to be kept within such limits as would make it acceptable to the Institution. For the same reason he has not dealt with wireless, submarine, or railway telegraphs. These subjects, although cognate to that of the subject of the paper, are branches of engineering of such importance as to deserve separate treatment.

The author has had to supplement the data he had in his possession with particulars which he has obtained from the principal officials of the Administrations of the Dominions and Colonies, and he takes this opportunity to tender his grateful thanks to all those gentlemen who have so kindly and willingly assisted him with information respecting their systems.

Throughout the paper it has been necessary to deal with the great Dominion of Canada separately. There the methods are based on American practice, as distinguished from British Post Office practice which is followed more or less throughout the other Dominions and Colonies. It will therefore be understood that where the "Dominions and Colonies" are referred to Canada is not included unless otherwise expressly stated.

No attempt has been made to deal with those special engineering troubles peculiar to the tropical Colonies, which were so adequately dealt with by Mr. Llewellyn Preece in his paper on "Telephone Troubles in the Tropics."*

If the paper appears to give an undue amount of attention to practice in South Africa and the Crown Colonies, it will be understood that this is because the author is more closely in touch with those countries than with the others.

No review of this subject would be complete without a reference to the great services the late Sir William Preece rendered to the Colonial Administrations during his lifetime. As far back as 1868 he undertook the training of a number of student engineers for the Government of India and soon after this date his advice was sought by practically all the Colonial Governments, including those in Australia, New Zealand, and South Africa, as well as those of the smaller Crown Colonies; and upon the advice he gave, not only were the foundations of many of the Colonial systems laid, but in many cases the superstructures also were built, and they stand to-day a not unworthy monument to his memory.

British Post Office practice.—From Sir William's association with the Colonial services and with the gradual standardization of materials and plant generally in the Home Department, and the publication by the Department of books of technical instructions, the Dominions and Colonies have got more or less into the way of accepting Post Office practice as beyond question. There is the feeling that, no matter what the subject may be, the practice laid down for it has been well thought out, and is the result probably of years of experience and of capable and careful research.

Colonial methods do of course vary in many matters of detail from those in vogue at home. Different peculiar local and climatic conditions have to be coped with. The Administrations of the Dominions send their chief technical officers around the world to see what is being done, and to cull from the various systems of the world those features which appear to them as being most advantageous for adoption in their own countries. Thus we find in the Dominions practice which is a mixture of British and American, and perhaps even a little Continental. But as the bedrock of it all, British Post Office practice is outstanding. It hardly matters what the difficulty may be, it is almost certain to be solved by a reference to "P.O. practice." If there is doubt as to how a particular material or piece of apparatus should be specified, it is at once got [illegible]

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* *Journal I.E.E.*, 1915, vol. 53, p. 545.

[illegible] their training in the various Home services. This still applies to appointments in the Crown Colonies, but it is only rarely the case now in the Dominions. The educational institutions of these countries have kept pace with the general progress, and they are not far behind those of the Motherland. In a general way, any youth starting at a Government primary school can, with the aid of Government bursaries, pursue his studies through the [illegible] University College where he can qualify in a degree of practically equivalent value to the B.Sc. of England. The son of well-to-do parents can similarly qualify in private schools, where Government aid is not given, up to the stage at which he enters the University College. The Colonial youth certainly has not the same opportunities of [illegible] cal training that a student engineer at [illegible] this is not so necessary as in the case of students in the heavier branch of power engineering, although it is of course a valuable asset in his training. So we find the youths of the Dominions qualifying in their respective engineering departments for even the highest positions in them. The author has in mind one Chief Engineer of a Dominion who has received practically all his training in the country in which he now holds this honourable position with much credit to himself. But these countries are what may be termed white men's countries. Their climates are sufficiently temperate for men of European birth or parentage to live and thrive in them, and what is of more importance, they can bring up their children there.

There are, however, several Colonies in the tropics, such as Nigeria, Gold Coast, Sierra Leone, Ceylon, British East Africa, Malay States, and the Colonies of the West Indies, [illegible] the heat, and the highly electrical conditions of the atmosphere in some cases, are so trying that Europeans must have the relief of a change to a temperate climate at frequent intervals. The Colonial Office Leave Regulations wisely make generous provision in this respect as regards some of these Colonies, but curiously the Regulations are not applied generally, and other Colonies [illegible] conditions are not so well off. For the filling of engineering appointments in these Colonies [illegible] that they offer sufficiently remunerative [illegible] they need not fear any dearth of applications from men of the right sort for these appointments. But there is a tendency to parsimony in this respect in many [illegible] in similar positions in England are paid, but [illegible] the cost of what practically amounts to maintaining two homes; and so in the end the Colonial engineer is rarely as well off financially as he would have been had he remained here. In the interests of Colonial engineering, and in the higher interests of Colonial administration, only the best men should be selected for these posts, and men of the best type who will always have reasonable prospects at home will not come forward unless the salaries offered are sufficiently tempting. From conversations the author has had with a number of Colonial engineers, he is convinced that generally there is not a sufficient margin of difference between the salaries they are paid and salaries in England, and this is surely a matter which should receive the consideration of the Colonial authorities. Low salaries for men in positions of responsibility are false economy.

In another direction the Governments of the Crown Colonies are very short-sighted. They do not encourage their engineers sufficiently to keep themselves up to date. Engineers do what they can in this respect by reading the current electrical publications, but to appreciate a new thing properly, an engineer wants to see it. Many engineers devote a good deal of their holidays in England to looking into engineering matters, but such enthusiasm and self-sacrifice should not be looked for as a rule. A technical officer, on whose initiative the engineering methods of a Department depends, should be specially commissioned by his Government to visit England at least every three or four years, to enable him to keep in touch with the latest developments.

Working staffs.—With well-trained staffs of European character, the engineers of Canada, Australia, and New Zealand are relieved of much of the worry which falls to the lot of the engineers in those countries where the bulk of the labour is black. In Australia there is an Arbitration Court, established by Act of Parliament, for the investigation and settlement of labour disputes, and any difficulties of this nature that arise between the Administrations and the working staffs of the Telegraph and Telephone organizations are referred to it. Questions of official status, and the nature of the duties to be performed by each section of the staff, promotion, salaries, travelling allowances, and indeed all the vexed questions which are the cause of friction between the Administration and the workers, are referred to this Court, and the Award of the Court is loyally accepted and acted upon by both sides. In New Zealand there is a Board of Appeal on somewhat similar lines.

In Canada there is a law under which employees can apply for a Board of Conciliation to discuss differences between themselves and their employers; but in regard to this, one high official in Canada remarks: "It is a debatable question whether it is of any advantage to either employers or employees."

In South Africa, and in most of the Crown Colonies, the rough labour is performed almost entirely by men of the native races, while generally the positions of control are held by Europeans. In Ceylon the main supply of labour is drawn from the South of India. The linemen are appointed from this class, and they are supervised by overseers of the "burgher" class, who are of native-Dutch and native-Portuguese extraction. All positions higher than that of overseer are held by Europeans.

In British East Africa and Uganda the unskilled labour is mainly obtained from the native negro population. Linemen are sometimes promoted from the construction gangs, but these positions are generally given to resident Indians, who are more intelligent. Inspectors are appointed from England.

In Nigeria the negro and negroid natives supply the labour. The more intelligent of these men are appointed as linemen. Inspectors and foremen are obtained from England, but men for these positions are now being promoted from the clerk class, which is drawn from the better educated of the natives.

In the Malay States there is a mixture of races, including the native Malays, Tamil Indians, and Chinese, but all speak the language of the Malays. Here the best of these men are selected for the positions of linemen and inspectors.

In South Africa practically all skilled work is done, and all supervising positions are held, by Europeans. The rough work is done by the natives, and many natives are also employed as unskilled linemen. The Cape "boys" of the Cape Province are decidedly more intelligent and reliable than the men of the other native races, and they make fairly good linemen. In the Orange Free State and the Transvaal the labour is mainly drawn from the Basuto and Zulu races, and in Natal it is got from the natives of Natal and Zululand. These natives, although sufficiently intelligent, are too indolent to be trained in any duties which call for a higher mental effort than that required to see and to use their hands. They are unable to read or write, and, generally speaking, they do not want to learn to do so. They have absolutely no conception of the technicalities of the work, or the "why" and the "wherefore" of things, and initiative and resourcefulness are quite foreign to their nature.

In white countries there is usually not sufficient work for all, and unemployment is always present, but in South Africa the position is reversed. All departments of industry are hampered by the disinclination of the natives to work. Where they are employed as linemen there is not that continuity of service which is desirable, and their utter lack of sense of responsibility is the cause of much anxiety to the engineer. Engineers in all the black Colonies have the same experience in this respect, and in some cases their difficulties are increased by the refusal of their Governments to provide adequate supervision. In tropical and semi-tropical countries it is only by constant and careful attention that the lines can be kept free from trees and undergrowth, and insect troubles; and without good supervision of the native linemen the lines are bound to suffer.

In Natal all sections of railway line with important railway signalling circuits and apparatus on them are in the charge of European linemen, who are assisted by native linemen. Ordinary line sections away from the railways are under native linemen, each having a defined length to look after. They are not allowed to touch the instruments. Many of the lines run across country, miles away from any road, and it is a native lineman's duty, usually under the direction of the postmaster of his headquarters station, to attend to faults on his section and also to keep his section of line in thorough order; but although he could be depended upon to do his best to find and remove a line fault, no dependence could be placed upon his movements when he was sent out on ordinary maintenance work. To ensure a better check upon the lineman, the "line inspection report" form, reproduced in the *Journal*,* was brought into use, and with it better work resulted.

The rates of pay to Europeans in the Dominions and Colonies vary generally with the cost of living, and any reference to them would be liable to be misleading, unless the living expenses and the local conditions in each case were also stated.

Sources of supply and delays in delivery.—Of all the Dominions and Colonies Canada is the only one that has made any headway in the manufacture of apparatus and material for telegraph and telephone purposes. Practically all wire, cable, subscribers' instruments, and manual exchange equipment used throughout the telephone services of the country are made in the Dominion. Automatic exchange apparatus, where this is in use, is obtained from the United States, but even this is now being assembled and built up in Canada. Copper wire, iron wire, and pole fittings are also made to a large extent. Telegraph apparatus is generally got from the States, and also the glass insulators so largely used. Porcelain insulators, where these are used, have been obtained to some extent from the Continent.

In Australia, cast-iron pipes, stoneware conduits, copper tapes and binders, and certain of the pole fittings are manufactured in the country. Prior to 1913, practically all the insulators used came from Germany, but insulators of both porcelain and stoneware are now being made within the Commonwealth. A fair amount of magneto telephone apparatus and switchboard material is obtained from Sweden, while some of the larger exchange switchboard plant and the Strowger automatic apparatus now being introduced come from America. Wire, cable, telegraph apparatus generally, and material of a kindred nature are obtained almost exclusively from Great Britain. It is the rule to invite tenders for all supplies and to give preference to goods of British manufacture.

The other Dominions and Colonies import practically all their plant. This is largely obtained from England, but quantities of telephone apparatus, especially, have in the past been supplied from both the Continent and the United States.

The great distances these countries are situated from their sources of supply, and the delays in delivery that have taken place, have been serious drawbacks to the smooth working of most of the Colonial engineering departments. The engineer in a Colony has to prepare his estimates of expenditure well in advance, but he cannot send off his indents for materials until the funds are actually sanctioned by his Government and voted by his Legislature. His estimates cover new works which cannot be proceeded with until the materials arrive, and as it takes anything from three to twelve months to get supplies from British manufacturers, it follows that in many cases the votes have lapsed to the Treasury before the materials reach him, the money is no longer available, and the work cannot go on until the "ins-and-outs" of the whole matter have been explained to the Government. In the meantime the workmen, who have been retained in

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* *Journal I.E.E.*, 1915, vol. 53, p. 556.

[illegible] from the Colonies. Before the War, it was no uncommon thing to hear an engineer say he would not put up with the dilatoriness of British manufacturers, and that he [illegible] instances orders were actually sent there.

[illegible] are got over by the establishing of "reserve stores" in which ample supplies are kept to meet all ordinary [illegible] considerable system should adopt. It involves the sinking of a certain amount of capital in the stock, but the convenience and the saving of money in workmen's wages are worth more than the amount of interest incurred. Under [illegible] and as they are issued the stores account is credited with their value from the funds provided for the works for which they are required. Delays in carrying out works are thus reduced to a minimum.

ADMINISTRATION.

The methods of administration throughout the Colonies are naturally varied to meet the local conditions, but in all the Dominions (with the exception of Canada) and also in all the larger Crown Colonies the telegraphs and telephones are combined with the postal service of the country, and the Postmaster-General is the officer responsible to the Government for the proper management of the organization as a whole. In some instances the office of [illegible] the permanent head of the Department is the Secretary [illegible]

Small Crown Colonies.—In some of the smaller Colonies telephone exchanges have been established by private companies as at Hong-Kong, Singapore, Port of Spain (Trinidad), and Kingston (Jamaica); but apart from these the telegraph and telephone systems are generally on so small a scale that they do not justify the appointment of a fully qualified telegraph or telephone engineer to control them, and so this duty falls to the hard-worked man of many parts, the colonial public works engineer, whose responsibilities in a Colony of the size I have in mind will include everything of an engineering nature from harbour works to electric bells. [illegible] telegraph or telephone inspector, who is often a man of good experience and who will at any rate relieve him [illegible] for the practical part of the work. For anything of a technical nature in which he is not quite [illegible]

[illegible]

Office side of the Department. [illegible] with engineers in charge of divisions or districts, each with the requisite staff of inspectors, linemen, and construction workmen under him. It is both convenient and economical to combine the staffs of the postal and telegraph and telephone services of a country under the one administration. Unfortunately, under this system there is a tendency for the commercial staff to assume functions which are liable to bring them into conflict with the engineering section, with a serious loss of efficiency to the latter. The officer who is responsible for the traffic and operating sections of the organization is inclined to see things only from the point of view of the traffic side, and the views of the engineer are therefore liable to be subordinated to his. It has been argued that the engineer should be directly responsible to the Colonial Secretary, but this arrangement would not be likely to work well in practice. It is most desirable that the relations between the head of the department and the engineer should be of an amicable nature. If the engineering section may be compared with the mainspring of a machine the administration may be looked upon as the governor, and it is only when there is a nice adjustment of the two parts that the smooth running of the machine is ensured. The efforts of the most capable engineering body in the world may be thwarted and the engineers themselves discouraged if there is undue interference and a lack of sympathy and support from the Postmaster-General and his staff. Proper consideration, and the recognition of good work done, will inspire a staff to its best efforts, while rough-shod methods will have the opposite effect.

Dominions: Telegraph administration.—So far as the telegraphs are concerned the administration is a comparatively simple and straightforward business. The main feature of note is that more care is given to the consideration of traffic matters than used to be the case. Following the example of the Home Department, more attention is given to comparing the merits of the various systems of telegraphy for the differing traffic conditions and to selecting that which is the most suitable in each case. Where the traffic is of sufficient volume special officers are appointed to watch it and to suggest the best routes for circulation and the most economical methods of dealing with it. The old practice of using one standard system, like the simple Morse in one or other of its forms, for all conditions of traffic is giving way and up-to-date type-printing systems are already in use.

Telephone administration.—Telephone [illegible] a more complex question. It is really a large subject in itself, and the scope of this paper will not allow the author to do more than deal briefly with it. In America more than anywhere else it has been studied and developed into what may be called a fine art, particularly by the American Telephone and Telegraph Company [illegible] extend over the whole of the United States. This Company's methods are the result of many years' experience [illegible] most complex amalgamation of telephone enterprises in [illegible] trict was controlled by one officer who was responsible to headquarters for all sections of the work, as was formerly the case under the late National Telephone Company's organization in England. But with the great development of the service which attended the Company's methods of management, this system proved to be unsuitable; it was not flexible enough to cope with the tremendous development. Specialization in the various branches of the work was found to be necessary, and a new system called the "Functional System" was introduced. Under this system the organization is divided into three sections, viz. traffic, engineering (or plant as it is termed), and commercial, and on the headquarters staff a specially qualified officer is placed in charge of each section. In each division the work is similarly divided; there is an officer in charge of each section of the work and each is directly responsible to the headquarters chief of his section. The duties and responsibilities of the officers of each section are carefully defined, but they are so correlated that a certain amount of overlapping is unavoidable and the success of the system really lies in the degree to which the three responsible officers are prepared to co-operate with each other. This applies not only to the three headquarters chiefs but also to the divisional officers. This feature of the system is claimed to be one of its chief advantages, inasmuch as it necessitates the full verbal discussion of a subject in all its bearings before it is reported upon, and much time and correspondence are thus saved.

Canada.—The telegraph and telephone services of Canada are quite separate from each other, as in the United States. Sections of the telegraph system scattered throughout the country and including a considerable mileage of submarine cable, are under the Government, and these are connected up through the lines of the public companies. By far the larger portion of the system is in the hands of the great North-Western Telegraph Company and the telegraph departments of the two great railway companies, the Canadian Pacific and the Grand Trunk. The telegraph organizations of these railway companies are responsible for both commercial and railway telegraphs, including all the other electrical systems and train dispatching services in connection with the working of the railways. The operations of the Companies are subject to the Dominion Railway Act, which is administered by a Board of Commissioners. There is no active competition between the different administrations. Each has its defined sphere of operations, and adequate communication between the different systems is provided. The form of administration adopted by the Companies is comparable with that of the railway companies of Great Britain. The Government Department is controlled by a general superintendent under the office of the Minister of Public Works.

The telephone services of Canada are partly in the hands of the Provincial Governments and partly under private and rural companies. In the Provinces of Manitoba, Alberta, and Saskatchewan they are controlled and mainly owned and operated by the local Governments, but there are also private telephone companies and municipally owned exchanges in operation. In the other parts of the country the telephones are in the hands of private companies, some of them operating over large areas of country. There is no real competition between the large administrations. Each has its particular area of operations, and the exchange and long-distance services are carried on without opposition. The rural companies are, however, frequently started in competition with the ruling company and intercommunication difficulties arise. The telephone companies operate under the Dominion Railway Act in the same way as the telegraph companies. Where a question of interconnection between any company's system and the long-distance lines of another company arises, the Board of Commissioners have the power to direct what shall be done and they determine the terms as to compensation on the merits of the case. The Bell Company of Canada connect both for long distances and local purposes with a large number of non-competitive systems, but the question of the terms upon which connections should be given with competitive systems is now before the Board.

In the three provinces already named each system is obliged by law to give connection to all the others, and the long-distance lines of the three provinces are also inter-connected.

The construction of rural lines by independent local companies for the purpose of giving telephone service to farmers is much encouraged by the various Provincial Governments, and in this respect Canada is a shining example to the other Dominions and Colonies. The Regulations of the Saskatchewan Provincial Government under which these companies are formed are typical. The companies are not allowed to operate their systems within towns or villages. The lines are built to a standard laid down in very complete specifications and instructions prepared by the Government Department of Telephones, and no rural line is allowed connection with a Government exchange or long-distance line unless it has been passed and accepted as satisfactory by an officer of the Department. A metallic circuit is required in each case, and not more than 10 instruments are allowed on one circuit. Poles for the construction of the lines can be obtained from the Government at cost price. The regulations are most comprehensive. They include full directions as to the procedure necessary for the formation of a company, and they are encouraging to a high degree to farmers to club together and provide their own communications at the lowest possible cost. The specifications are accompanied by drawings and they, also, are so comprehensive that but little difficulty is experienced by the farmers in constructing their own lines themselves.

The form of administration adopted by most of the administrations is on "Territorial" lines, but in some cases it is "Semi-Functional."

Australia.—In the great Commonwealth, the telegraphs and telephones are a close monopoly under the Post Office. The Postmaster-General is the Parliamentary head of the Department, and the permanent head is the Secretary. In each of the States the local head is designated the Deputy Postmaster-General, and all sections of the Department, including the Engineering Branch, are under his control. The Chief Electrical Engineer at Headquarters is responsible to the Secretary, but his position is largely consultative, and there is not that direct line of control over the engineering organizations of the various States which is usual. He communicates direct with the head engineers in the States upon all technical matters, but notwithstanding this, there has not been that close co-ordination of [illegible] a centralized form of administration. The system no doubt has its root in the form of Government adopted under the constitution of the Commonwealth. This, as is well known, is on [illegible] the individual States [illegible] [illegible] degree of centralization of administration which has resulted under the unification principle adopted in South Africa. There, the original [illegible] and they are completely subservient to the headquarters' administration.

Under the Department's Regulations, it is provided that lines for public use in country districts which may not be immediately remunerative to the Department, may be erected under a system of guarantee, under which the Department bears 50 per cent of the estimated annual loss. This loss is computed on the estimated cost of construction and the cost of maintenance and operating, and the balance of the loss is borne by those interested in the construction of the lines. In other cases, the local residents are permitted to erect the lines themselves, to the Department's specifications, and at the Department's expense, provided that the work is carried out at such a cost as will bring it within the guarantee Regulations. It is found that the local people can carry out the work at a cheaper rate than the Government Department, owing to their being in better touch with the local labour supply, and with the transport and other local facilities.

The fullest encouragement is given to persons living in the country to erect their own lines, either individually, or conjointly with their neighbours, for connection with post offices or exchanges, and the Department furnishes applicants with all the information they may require, both as to the best means of establishing connections, and as to the class of construction best suited to their requirements. Where such lines are erected over private lands, the method of construction is at the option of the persons constructing the lines, but where they pass over public land, or across railways, or roads or places accessible to the public, the method of construction and the poles and other materials [illegible] to the approval of the Department. If poles belonging to the Department are already in existence, the lines may be erected on them at the cost of the persons concerned, and subject to a nominal annual rental for the use of the poles, but in this case the direction and control of the work of erection rests with the Department's officers.

The railway lines are administered separately from those of the Post Office. In certain cases, the Post Office lease wires to the railways, or erect wires for them on terms which are mutually applicable, but there is no divided control over any of the Department's lines.

[illegible] New Zealand the Postmaster-General is a political officer, and the Secretary is the permanent head of the Administration. In the districts the chief [illegible] be said to follow [illegible] panies for the establishment of rural or other lines. Under the Telegraph Act no person or persons may construct telegraph or telephone lines for hire or profit, but there is no hindrance to persons erecting lines for their own use. Many such lines have been put up by farmers in the back blocks of the country where the Government do not feel warranted in spending money on lines which offer little prospect of paying their way. Such lines usually terminate in a Government office or exchange where they are given connection with the Government system. They are usually built as cheaply as possible, and the service is generally inferior and faults are of frequent occurrence. In some cases the farmers establish small local exchanges to which the Government run trunk circuits to give connection with the main system. The farmers make their own arrangements as to the working of the local exchange, and they pay the Government only for such calls as go through on the trunk lines. In other cases the Government connect up with the private lines one or two miles away from the exchange as may be arranged. The Government exercise no supervision or authority over these private installations. The Postal Department have no control over the lines or electrical systems of the railways of the country except in cases where wires are erected on the Department's poles for the use of the railways, and in these cases the railways pay for the maintenance of the wires. There is no divided control over the lines and, generally speaking, each administration has its own separate pole lines and arrangements.

South Africa.—In South Africa the telegraphs and telephones are also under the Postmaster-General, who is the permanent head of the Administration, the political chief being designated "Minister for Posts and Telegraphs." Of all the Dominions outside Canada whose telephones are administered by a Government department South Africa is the first to adopt the "functional" system. Prior to the unification of the South African Colonies each Colony had its separate Administration. With the advent of the Union the separate administrations ceased to exist, all were merged in the one central administration and a system closely allied to the "territorial" which had been in force in the Cape Colony was applied to the whole of the Union. The country was divided into seven districts for administrative purposes, and the officer in charge of each was designated "surveyor and district engineer." Under him an engineering officer was appointed, who was responsible to the "district engineer" for the engineering side of the work. He did not, however, come directly under the chief engineer; all correspondence and official communications between the district and the headquarters office passed through the "surveyor and district engineer." The chief officer of the district [illegible] expected to be an expert in all the intricacies of Post Office work, in telegraph and telephone traffic arrangements, and also in the technicalities of the engineering side of the great Department. How many masters he had to serve at headquarters it would be hard to say, but it is quite likely that in an extreme case he would have to address the Postmaster-General, the Secretary, and the Chief Engineer on different aspects of the [illegible] With the great development of the telephone system this method of administration was [illegible] a tour of [illegible] organisations of Europe and America by the chief engineer, the "functional" system was recommended by him and adopted by the Postmaster-General. It was introduced about three years ago and the Postmaster-General when in England last year informed the author that the system was working with the greatest satisfaction.

Under a commercial administration it can easily be conceived that this system will work satisfactorily. Any disinclination on the part of an officer to work up to the standard degree of earnestness of co-operation would no doubt result in his being degraded, but Government officials could not be treated in this summary manner. Moreover, the capacity for co-operation varies with the individual, and is as varied as human nature itself. Obviously, therefore, this system is only suitable for adoption where the organization is on a sufficiently large scale. There must be a big field from which to select the responsible officers. In South Africa the great expansion of the system called for a new method of administration, each stride in the development brought increased complexity of apparatus and plant; greater specialization was required and the time was ripe for a change. But the change proposed was a very drastic one, and it required great courage on the part of the chief engineer to bring it forward, and on the part of the Postmaster-General to accept and adopt it. On the part of both there was a feeling of absolute confidence in the zeal and in the capacity of the splendid staff of the Department to rise to the new conditions and to show that a system which is a great success under commercial conditions can be equally successful when applied to a Government Department.

Amalgamation of Government railway telegraphs with postal telegraph systems.—In practically all the Colonies and Dominions the railways belong to the State, and in some of the smaller Colonies a feature of the Administration is the amalgamation of the railway telegraph engineering and electrical signalling systems with the Engineering Department of the Post Office. This arrangement was in force in Natal during the whole of the author's time there, and it worked very satisfactorily for both railway and postal departments. The maintenance expenditure was apportioned as nearly as possible so that each department paid its fair share. The cost of new work was met by the department incurring it. A new pole line erected for the joint use of the two departments was paid for in proportion to the number of wires erected for each department. All railway stations were also public telegraph offices. Public telegrams were sent over the railway department's wires, which were in all cases connected through to Post Offices, so that each station was able to send its public telegrams direct without retransmission to the postal system. This also facilitated the testing of railway wires, which was done entirely by the Post Office. The Post Office paid the railway department a small rate per message for all public telegrams dealt with at each station, and in this way the railway department received payment for the work done by its officers. The system worked most satisfactorily and the public reaped the advantage which arose from every railway station being also a public telegraph office.

It was a cardinal rule that the railway department's engineering work should always take precedence, and it did not matter at what time, day or night, a fault occurred on the railway department's electric train staff system, it was the sectional lineman's duty to attend to it at once. The arrangement undoubtedly resulted in the saving of money to the Colony. The same pole lines were used for both postal and railway wires, and there was no clashing of interests when additional wires had to be erected, and no obstacle to the best and most economical proposals being made for any scheme put forward by either railway or postal department. There was one staff for the engineering work of both departments, and the overlapping of duties which would have resulted if each department had had a separate staff was avoided; the same standard types of materials, in the charge of one stores department, were used on both departments' systems. All electrical signalling systems are of a cognate character and come naturally within the scope and training of telegraph engineers and linemen, and any Colonial Administration which may contemplate such an amalgamation need have no fear for the results provided a capable and well-organized staff is available.

Electric lighting in charge of telegraph and telephone engineers.—Under some administrations telegraph and telephone engineers are required to carry out the departmental electric lighting work, and it is a highly debatable question whether this principle is a good one. With the use of power plant in central battery systems of telegraphy and telephony and also in railway signalling work engineers must have a knowledge of machine-generated electricity which was not essential in the old days, when their one and only source of energy was the primary cell. Between the power requirements of telegraphy and telephony and the complexities of the various systems of lighting there is, however, a wide difference. The author's opinion is that in the specialization which is necessary to-day in telegraphy and telephony it is too much to expect an engineer to be expert also in the lighting and power applications of electricity in the larger sense. The practice in this respect throughout the Dominions and Colonies varies. In Canada most of the administrations have their lighting done from outside, but there are exceptions to this rule.

In Australia all installations are put in by a Government department corresponding with the Government Office of Works of England, but the Postal Department's engineers are responsible for the maintenance of the installations.

In New Zealand the Department's engineers are responsible for the electric lighting. In the case of a large new building the installation is, as a rule, done by the Public Works Department, but the upkeep afterwards is in the hands of the telegraph and telephone engineers. They also do the installation work in smaller buildings, carry out all alterations and additions to lighting arrangements, and attend to all maintenance requirements. In South Africa the lighting of all Government buildings, apart from the railways, and including those of the Post Office, is done by a special branch of the Public Works Department. In the Crown Colonies the practice varies, but it is generally on the lines followed in South Africa.

ENGINEERING.

Overhead construction.—There is practically no overhouse construction in any of the Dominions or Colonies, and the chief difference in the construction of pole lines lies in the question of the pole employed. The [illegible] [illegible] whether or not a country is a timber-producing one. Where timber is plentiful and there are no local drawbacks to its use, wood poles are the rule, but where it is scarce or not of suitable size or quality, or where it is liable to be attacked by white ants, or destroyed by grass or bush fires, iron poles are used.

White ants abound in practically all the tropical Colonies, and while it is usual in such countries to find an indigenous wood which is more or less immune from their attacks, like the teak-wood of Burmah, the cedar of British East Africa, and the "sneeze-wood" of South Africa, it is not always suitable for use as telegraph poles. In several of these Colonies there are large indigenous forests where the growth is so dense and heavy that it is a very costly matter to cut a clearing through it when a new line has to be erected. The practice in Nigeria, which is probably unique, is to cut a clearing from [illegible] to 200 feet in width so that the wires may be well clear of the branches of trees. The cost of maintaining these clearings is very heavy. A peculiarity of these forests is that there is no uniformity either of size or of shape in the trees. Many will be over 200 feet in height by eight or more feet in diameter. Below these there are trees of every other conceivable height and shape, and the whole forest is interlaced with an impenetrable mass of climbing and twisting growth. To obtain any considerable number of poles of anything like uniform size and length would be impossible unless a very large area of forest were cleared, and the cost of this would be prohibitive. South Africa is not what may be termed a timber country, although there are forests of indigenous trees here and there. Amongst these the "sneeze-wood" is the only one that will withstand the ravages of the white ant for any length of time, but even this wood is not free from attack. This ant will drive its tunnels from the bottom of the pole to the top, through the outer rings of the wood, but as it approaches the core of the tree it will stop, because the core is too hard for it to penetrate. The core of the "sneeze-wood" is almost as hard as iron while yet as flexible as whalebone, and the author has heard of only rare cases in which the ant has been able to eat into it.

The author has known poles which were originally 6 or 7 in. at the bottom tapering to about 4 in. at the top reduced in this way to an average of about 3 in. The pole became so slender that even the weight of a ladder leaning against it would cause it to bend over like a whipstick. They were also liable to be destroyed by grass fires in the dry winter season. It was the rule to clear the ground of all grass and undergrowth for several feet around each pole with hoes, so that a fire would not actually reach the pole. Many poles were burnt off several feet above the ground due to burning embers carried by the wind into the cracks and crevices in the poles and fanned into flame there by the wind. The author has also [illegible] poles [illegible] destroyed in the same way. These "sneeze-wood" poles were of rough appearance, crooked and gnarled, but they served their purpose well in the construction of the lines that were built throughout the country in the early days. The author does not know that any method of treating these poles, such as the injection of creosote or other substance obnoxious to the white ant, was ever tried, but even if this were effective so far as the ant is concerned, there would still be the liability to destruction by grass fire, and the author's sympathies are with the engineer who prefers not to run this risk. The poles were not suitable either in height or strength to carry more than a few wires, and with the gradual opening up of the country they were replaced with tubular iron taper poles imported from England. In recent years wood poles from eucalyptus trees grown in Government plantations in the Cape Province have been tried experimentally on certain lines in the neighbourhood of the plantations, but the experience so far has not been favourable. Iron poles are now generally used throughout the country and in most of the Crown Colonies.

In British East Africa and Uganda there is a "live" pole in use which is perhaps unique in its way. Some years ago a temporary line was erected with poles got from a species of natural wild fig-tree, and these poles, when planted, unexpectedly took root and became trees. These poles, although not absolutely immune from the attacks of white ants or decay, were found to stand much better than ordinary "dead" wood poles which either rotted or were destroyed by white ants in a very short time after their erection. Benefiting by this experience, the administration built about 1,000 miles of line with this type of pole. They were cheap and they have served their purpose well in the development of the country during a period when funds were limited. They have their disadvantages, however. They are liable to become top-heavy and blow over during storms. The leaf growth is also a source of trouble, as if it is not very carefully watched it leads to serious loss of current in wet weather. This is so much the case that most of the lines on these poles have to be worked by vibrator instead of the ordinary Morse system. With improved financial conditions these colonies are now using tubular iron poles.

POLE LINES.

Crown Colonies and South Africa.—There are two types of tubular iron poles with cast-iron bases and wrought-iron taper upper tubes in general use in the Crown Colonies. The advantage in the tapering top is that it combines strength with lightness. The taper is lap-welded in machines specially designed for the purpose. In the original joint the space between the tube and the base was filled with a sulphur-oxide-of-iron cement, but in nearly all poles ordered now either the screw ring joint, or the taper ring joint is used. Personally the author prefers the latter because it fits automatically and it eliminates two items from the stores list, namely, the separate screw ring and the screw-ring spanner.

In all these poles the cast-iron base is of sufficient length to keep the wrought iron tube out of the ground when the pole is planted to its proper depth. The depth of the socket varies from 6 in. in a 20-ft. pole to 12 in. in a 30-ft. pole.

All cast-iron bases were originally made without the wrought iron band which is now used and which is shrunk on to the top end of the base. Before the band was brought into use it was a common thing for a base to split at the socket in cold, gusty weather, but the band entirely prevents this.

The top end of each pole is bossed and a wrought iron lightning rod about 18 in. long by ½ in. diameter is usually driven into a tapered hole in the boss. Sometimes, however, an insulator spindle is screwed in, but this is a practice not to be recommended. Where lightning storms are frequent the insulator runs great risk of being struck, and in any case a wire running along the tops of poles is very much in the way of the lineman.

One type of pole has its base pointed, the point being solid for about 5 in., so that it can be driven into the ground by means of a special rammer which is dropped inside the base. A wooden disc about 2 in. in thickness is first put into the base to take the impact of the blows from the rammer off the cast iron. Where the ground is at all sandy or marshy a ground plate can be used. It is slipped over the bottom end of the base and wedges up against a narrow bead on the casting about 12 in. from the top. This pole will carry a horizontal load of about 80 lb. at a point 12 in. from the top.

TABLE 1.

Dimensions, Weights, and Carrying Weights of Standard Tubular Taper Poles.

Length of Pole		Length of Taper Tube		Length of Base		Diameter of Tube at Top	Diameter of Tube at Bottom	Size of Steady Plate	Weights			Carrying Weight * (Factor of Safety of two)
									Tube	Base	Plate	
ft.	in.	ft.	in.	ft.	in.	in.	in.	in. sq.	lb.	lb.	lb.	lb.
18	0	14	0	4	6†	$1\frac{5}{8}$	$3\frac{1}{4}$	12	44	56	12	100
20	6	16	6	4	6†	,,	,,	12	54	56	12	80
19	4	13	0	7	0	,,	$3\frac{5}{8}$	21	76	123	15	230
20	0	13	6	7	0	,,	,,	21	64	100	15	200
20	0	13	6	7	0	2	$4\frac{3}{4}$	28	118	189	36	500
20	0	11	6	9	0	3	6	36	140	396	100	900
25	0	18	10	7	0	$1\frac{5}{8}$	4	24	135	140	24	200
30	0	24	0	7	0	2	5	28	250	190	36	250
35	0	29	0	7	0	,,	6	28	360	195	36	250
40	0	34	0	7	0	,,	6	28	420	195	36	150
40	0	35	3	7	0	,,	5 $4\frac{5}{8}$	28	225 130	195	36	140
						(Upper tube in two parts)						

* A test of twice this weight applied 12 in. from the top of the tube should not give a perceptible permanent set.

† With pointed end for driving into ground.

The standard type of pole used has a cylindrical cast-iron (parallel) base with square flange at the bottom end to which a buckled base plate is bolted.

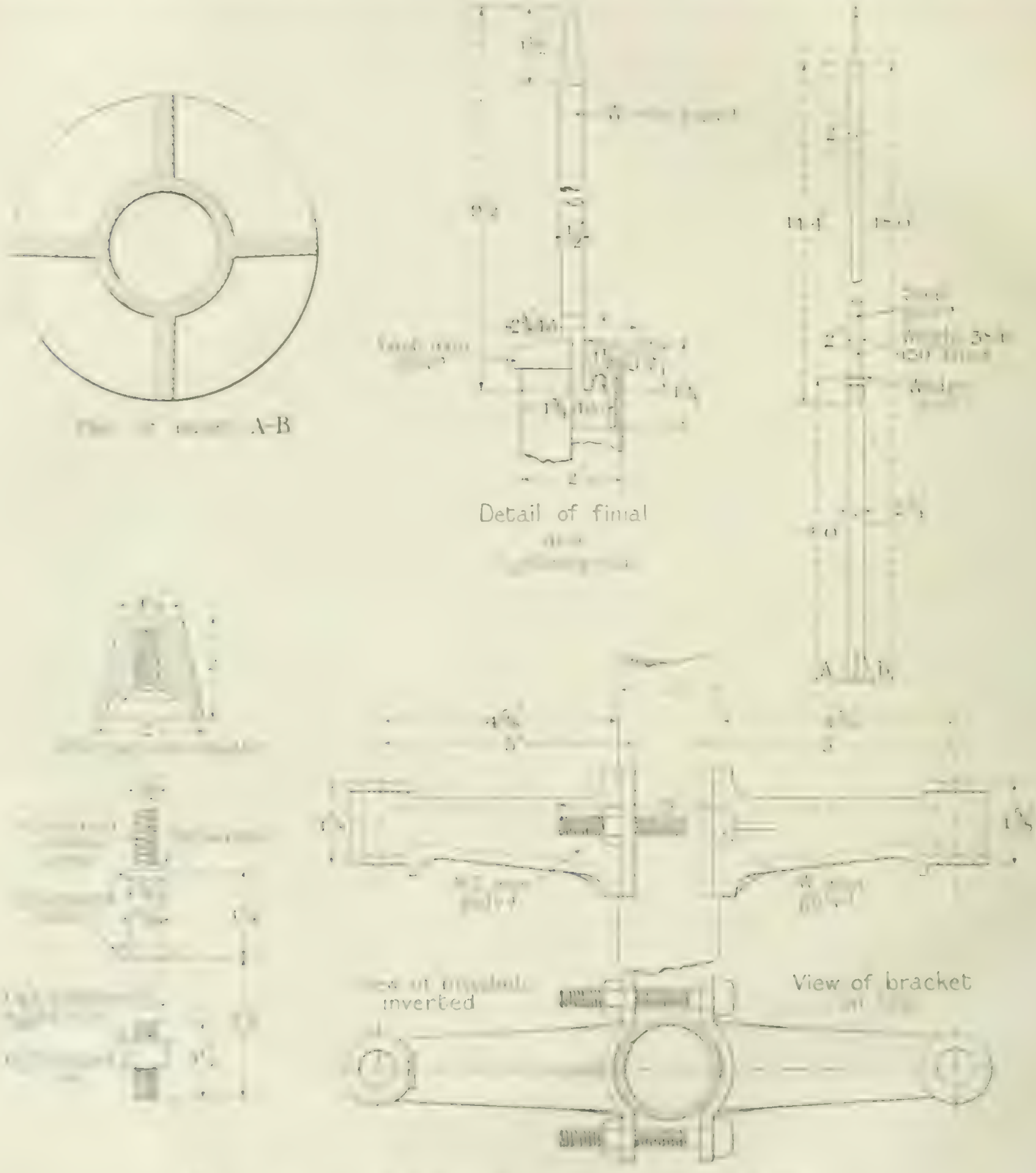
Poles of this type are made in a number of standard lengths and strengths. Where the length is 40 ft. or over, the upper part is made in two or more sections. Table No. 1 gives particulars of a number of standard sizes of poles of these types. The cast-iron bases and buckled plates are usually dipped in Angus Smith's compound, while the tubes are dipped while hot in hot linseed oil. A factor of safety of 2 based on a wind pressure of 17 lb. per square foot is sufficient for these poles in countries where there are no snow and ice accumulations to be taken into account. Where snow and ice occur a factor of safety of 4 should be allowed.

The cast-iron bases used in South Africa have circular flanges at their bottom ends, with four strengthening webs extending from the flanges about 18 in. up the base. This flange is of larger area than the square flange and can be used without a base plate where the ground is sufficiently firm. For this reason it is called the O.B.P. (optional base plate). Fig. 1 shows a light pole specially designed for South Africa. It is used on farmers' lines and carries one or two pairs of wires between main routes and the homesteads. It is 18 ft. in length and has a wedge joint. It will carry wires having a total lateral stress of about 80 lb. 12 in. from the top. It is probably the lightest and cheapest pole used in telephone practice anywhere. The upper tube is high-grade steel galvanized, and the lower section is cast iron. The cap is of cast iron and the lightning rod wrought iron. The bracket, spindle, and insulator used with this pole are also shown in the figure.

There is a parallel pole of a more ornamental type which is used for special street work in South Africa. There is no cast-iron base with it, but it is protected from corrosion at the ground line by means of a sleeve which is shrunk on. It is 26 ft. in length and will bear a maximum load of about 300 lb. at the top when planted 4 ft. in the ground. Where poles of similar type have been planted without the sleeve protection, corrosion has often taken place at and above the ground line. This has been prevented by the use of cast-iron sleeves made in two longitudinal half-sections with their edges overlapping. When the two half-sections are screwed together they have a neat cylindrical appearance. The small space between the sleeve and the pole is caulked with yarn and red lead and painted over.

Fig. 2 shows a tubular iron strut used with iron poles. The object of the screwed eyebolt at the top end is to give a margin for the adjustment of the strut at the point of attachment to the clip.

A lantern slide shows an H-pole on the line carrying telephone trunk wires between Johannesburg and Pretoria. This was originally a single 22-ft. pole line carrying four wire lines. It was converted into an H-pole line by a second line of similar poles being erected parallel with [illegible] Hamilton pole [illegible]. These consist of riveted tubes of steel sheet fitting into cast-iron sockets having cast-iron



[illegible]

its original one. This consisted of [illegible] galvanized [illegible] wire.

In most of the [illegible] tubular poles of the type [illegible] by the Indian Government and known as the [illegible] base-plates. A telescopic pole is about [illegible] ft. out of the ground, and it comprises eight sections each 8 ft. long. The poles taper from about [illegible] at the bottom to [illegible] at the top. They are jointed together by the upper end [illegible] each case being driven over the next lower one, and each joint is strengthened by a stiffening hoop shrunk on. Each section has its own cast-iron socket with sole plate which is known by the letter corresponding with the tube it fits. The sole plate screws on to the socket. The top of the pole is fitted with a cast-iron cap with lightning rod which is driven into the top of the tube. The above-ground parts are always galvanized, while the sockets and plates are dipped in Angus Smith's compound.

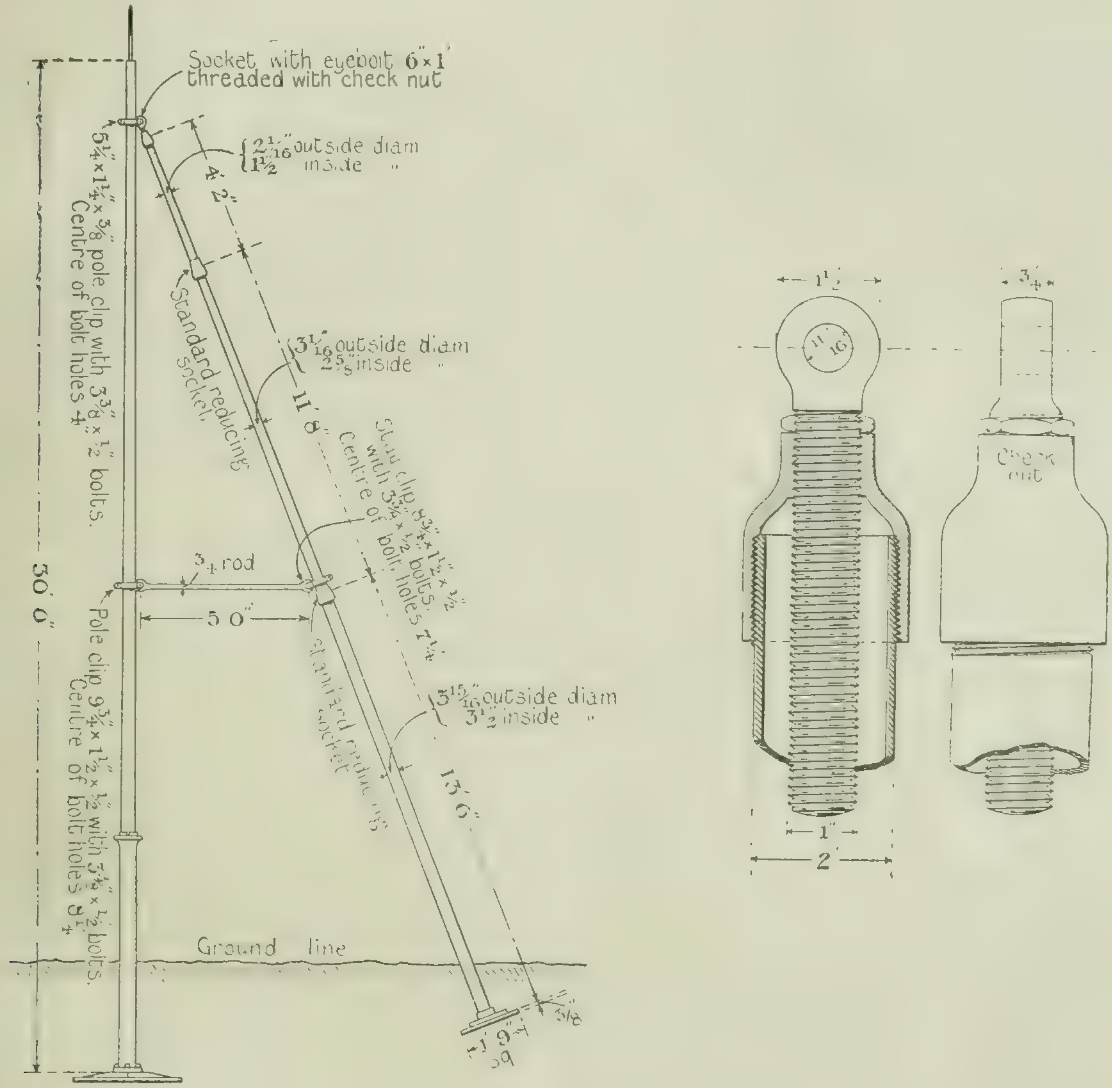

Socket with eyebolt 6"×1" threaded with check nut
2 1/16" outside diam
1½" inside "
4'·2"
5¼"×1¼"×⅜" pole clip with 3⅜"×½" bolts. Centre of bolt holes 4"
Standard reducing socket
3 1/16" outside diam
2⅝" inside "
11'·8"
Stay clip 9¾"×1½"×½" with 3¾"×½" bolts. Centre of bolt holes 7¼"
¾" rod
5' 0"
30' 0"
Pole clip 9¾"×1½"×½" with 3¾"×½" bolts. Centre of bolt holes 8¼"
Standard reducing socket
3 15/16" outside diam
3½" inside "
13'·6"
Ground line
⅜
1' 9"
1½"
¾"
11/16
Check nut
1"
2"

FIG. 2.—Tubular iron strut for 30-ft. pole.

The number of poles to the mile varies with the class of line. Twenty to the mile may be said to be the lowest number that is allowed on a light country line, but the author knows lines on which the average per mile is much below this figure. From this the number ranges up to 40 to the mile. Over even country the spans are restricted to whatever the standard for the line may be, but in broken country they may vary from the normal up to 400 and more yards. The author has had experience of spans up to 800 yards in length over rivers and ravines standing quite satisfactorily for many years. Hard-drawn copper wire was used on spans up to 300 yards, whilst above that length bronze was used. Copper wire can be fully relied upon for long spans so long as a reasonable factor of safety is allowed. In a country where snow is almost unknown this may be as low as two, but it should include full allowance for wind pressure. The poles are specially stayed, double width spacing is given on the arms, only one quality and gauge of wire is erected, every care being taken to adjust all the wires to the same dip, and no joints are made in the spans. With these precautions the wires all swing in unison and there is no trouble.

The stays used throughout these countries are of British Standard types with tighteners and with iron anchor plates which are usually tarred. Where the stay wire is fixed to an iron pole it is made off over a special clip. It is bad practice to fix it over an arm or bracket as is often done.

[illegible] tightener.

Where iron poles are employed near the sea they can only be preserved from corrosion by being frequently painted or tarred. The author has tried every kind of paint for this purpose, but he found none to stand any better than coal tar applied in the heated state. It is much cheaper than paint, and where native painters do the work the waste which is inevitable is not so serious a loss. Reinforced concrete poles would be more serviceable than iron in these situations, but the weights of these poles in proportion to their strengths are against them for lines where the difficulty of transport is a serious factor. It seems to the author that there should be a field for these poles in countries where the principal ingredients, cement and sand, are available, so that with a portable pole-making plant the poles could be made in the vicinity of the line in [illegible]

Hollow reinforced concrete bases made in moulds locally and fitted with wood tops are sometimes used. Discarded railway rails are also used at certain places, the rails being set with the web of the rail at right angles to the direction of the line. Planted the other way about they are liable to bend over in very windy weather.

Canada.—In Canada wood poles and arms obtained from timber grown in the country are used on both telegraph and telephone lines. There are no iron or reinforced concrete poles in use.

Each railway company's telegraph lines are erected on the right of way of the railway concerned. Where it is necessary to connect the wires at a central office in a town they are either taken on a pole line through the streets or a cable is laid underground according to the requirements of the municipality. The lines of the Great North-Western Company follow the highways except in cases where the Company have contract privileges for the construction of lines along the railways, but it may be said of Canada as a whole that there are few highway telegraph lines in the country.

The main telephone lines follow the public roads. Short cuts across country, except in the case of rural companies' lines, are resorted to only in special cases and where the right of way can be obtained.

These wood poles are generally of cedar. They are straight and of good appearance and are not treated with any preservative. White ants are unknown. Damage by fire is of rare occurrence on the railway lines, but in some of the districts poles are occasionally destroyed by prairie fires. The poles generally are cut to an apex at the top, the apex being at right angles to the arm, but they are not [illegible]

The standard lengths of poles used by the different administrations vary considerably and this may be said of many of the other constructional materials employed. The standard length pole of the Canadian Pacific Company is 25 ft., but in broken country the poles vary up to [illegible]

[illegible] With other administrations 30 to 35 ft. is usual for [illegible] their rural lines 20 and 25 ft. lengths are commonly employed. Separate pole lines are generally provided for rural and long distance circuits. Pole steps, in some cases of wood and in others of iron, are fitted to office and terminal poles, the bottom step being 3 ft. from the ground.

The practice in respect of the providing of earth wires on poles varies, but it is nowhere the rule to earth wire every pole. Under one telephone administration every tenth pole and also the pole on each side of a "test" station are fitted with No. 9 galvanized iron wire stapled every 2 ft. up the pole and extending 3 in. above the apex of the pole. The wire is kept at least 2 in. clear of the cross-arms and is given two hand turns under the bottom of the pole. In another case an earth wire is fitted every half mile only.

The spacing of the poles is varied in the different administrations, and it of course again varies with the class of line. One system, which is typical, allows 40 poles to the mile on heavy routes, 36 to the mile on less heavy, 32 to the mile on lighter, and 30 to the mile on light routes. The first and second, and sometimes the third, spans in each mile are usually shorter than the others. At road and railway crossings poles of suitable length are used to give clearances of 16 ft. over roads and 25 ft. over railways when the ultimate lowest cross-arm has been fitted. A clearance of 3 ft. is allowed either over or under when the wires of another administration are crossed.

Stays—or guys as they are termed—and struts and overhead stays attached to stubs where there is obstruction to the use of ordinary stays, are liberally used on angle and terminal poles. At road crossings and at acute angles longitudinal stays are fixed. In the case of a crossing the stay is taken from the top of the second pole to the butt of the first at each side of the crossing. In some cases a similar stay is fixed between the second and the third poles. Anchors of both wood and iron are used, the latter generally being of the patent type which is screwed into the ground. The eye of the anchor rod, which is fitted with a thimble, is brought just clear of the surface of the ground. The stranded stay wire is secured both at the pole and at the rod by means of a clamp held by bolts. Stay tighteners are not used.

Australia.—Both wood and iron poles are used, the selection depending generally upon whether or not dangers from white ants or bush fires have to be met. Several types of iron poles are employed, the principal being the Siemens taper pole with cast-iron base and screw-ring joint. For light lines the Oppenheimer iron pole, iron tubing, and old railway rails are also used. The Oppenheimer pole has a cast-iron base shaped like a dart with moderately sharp cutting edges which permit of its being driven into the ground. In the upper part a socket is formed into which the wrought iron tube is fixed by means of iron wedges.

All the wood poles used are obtained from trees indigenous to the country. There is a great variety of these and they are practically all of the hard wood class. They have not the straight clean appearance of the red pine pole used in England, but they are required to be straight and round, and as free as possible from irregularities and inequalities. Up to the present no treatment for the prevention of decay has been applied, but the question of introducing creosoting plant for this purpose at the larger centres is under consideration. In districts infested with white ants all poles are protected from their attacks by the application of a solution of arsenic (1 lb.) and caustic soda (2 lb.) dissolved in 1 gallon of water. The pole is well coated with this mixture by means of a long-handled tar brush for a distance of 18 in. above and 18 in. below the ground-level. The solution is given a few hours in which to soak into the timber, when it is given a coating of coal tar composition consisting of gas tar (7 parts), Stockholm tar (3 parts), and fresh-slaked lime (3 parts). The ground for a distance of 1 ft. around the pole is well sprinkled with the exterminator and this is covered with 9 in. of unpoisoned earth. Another method is to bore one or more holes with a ⅝ in. auger in a downward direction to the centre of the pole, and to fill the holes with the exterminator, the holes afterwards being plugged with hard wood plugs which are gently driven in and then cut off flush with the pole.

Poles vary from 20 to 75 ft. in length and from 5 in. diameter at the small end and 8 in. at the butt, to 12 in. at the small end and 20 in. at the butt. The minimum height from the ground of the lowest wires along the road is 12 ft. and at the road crossings 18 ft. Road routes are generally followed, but it is found to be more economical to erect the poles within the railway reserve when this is practicable. All wood poles are provided with lightning conductors of No. 8 galvanized iron wire fixed with staples 2 ft. apart. The top of each pole is cut to an apex which is placed at right angles to the line. It is coated with coal-tar composition and fitted with a galvanized iron roof of sufficient size to project 2 in. beyond the pole on all sides.

Where poles are stayed anchor logs not less than 9 in. diameter and 4 ft. in length with 4 in. square washers are used. The stay wire is attached to the eye of the rod, through a thimble, and is secured on itself by means of a stay clamp. Stay tighteners are not generally provided. Where the stay wire is attached to the pole a half-inch check bar is passed through the pole to prevent the stay wire slipping down, and the end of the stay wire is clamped as at the stay rod.

New Zealand.—New Zealand has a greater variety of types of poles than most countries. Poles of wood, tubular iron, reinforced concrete, and discarded railway rails are in use. The wood poles are mainly got from indigenous trees, the totara and silver pine being found to be the most suitable. They stand well in the ground, but timber generally is scarce and the supply of trees suitable for poles is limited. A good many poles of ironbark wood have been obtained from Australia. Other kinds of Australian woods have been tried, including stringy bark and jarrah, but they do not stand so well. The poles are generally sawn square, although both silver pine and ironbark poles when obtainable in lengths within 25 ft. are used in the natural round state. The poles are not treated in any way. Charring the butts has been tried, but it had no good effect and was even found to be harmful. There are no white ants in New Zealand and poles are but rarely damaged by fires. The standard lengths of wood poles in use are 18, 20, 25, 30, 35, 40, and 45 ft. and they are of varying strengths to meet the loads they have to carry. The poles are not earth-wired.

Tubular iron and steel poles have come more into use within the past few years. They are of both solid drawn and lap-welded types, although not of the standard taper pattern so much employed in South Africa and other countries. They are used in the larger towns for telephone exchange distribution purposes, also in the lighter sizes on some light country lines where it is advantageous to use them owing to the ease with which they can be transported and handled over rough country.

The reinforced concrete pole used is of solid construction, the cross-section being rectangular. When erected the longest side of the pole is placed at right angles to the line. The poles are made of different strengths to carry specified working loads, and over this load a factor of safety of 2·5 is allowed. The dimensions and strengths of two typical 25-ft. poles are :—

(1) 7 in. × 4 in. at the butt, tapering to 3½ in. × 3 in. at the top. Weight 490 lb. Working load 150 lb.
(2) 7 in. × 5½ in. at the butt, tapering to 5 in. × 3½ in. at the top. Weight 720 lb. Working load 250 lb.

Hollow concrete poles are not employed.

Poles of 52 lb. and 70 lb. discarded railway rails are largely used and are said to make splendid lines. Where extra strength is required, as at angles, two rails with their flanges bolted together are often used, and where a line is required to be specially strong every fifth pole is doubled in this way. Poles of this type have been used for a great many years and are so favoured that they would be in general use but for the fact that they are not available in the quantities required. Special castings are made to attach the arms to these poles. The pole lines generally follow the public roads, and the right of way for the erection of lines is subject to the sanction of the local authorities controlling the roads.

POLE FITTINGS.

Crown Colonies and South Africa.—There are many types of iron brackets and arms available for use with iron poles, and South Africa may take some credit for having helped to evolve a number of useful improvements to these fittings.

The bracket shown in Fig. 1 is of malleable cast iron. It is typical of many other patterns which vary mainly in the size of the seat. A similar bracket is made for four wires. For one wire only a single bracket with a back strap is used. On this bracket there is a small projection which locks the spindle nut and so prevents it from getting loose owing to vibration.

For a wood arm Jobson's combination bracket is a useful fitting. This was originally made with straight fixing bolts, and it is still used in this form by some administrations. In South Africa it gave much trouble owing to the arm shrinking in dry weather and causing the clamp to become loose. On angle poles this often allowed the arm to cant and even to twist right round. To prevent this and to enable the clamp to be tightened up on the pole independently of the arm, the author's old chief in Natal, the late Mr. T. T. Hardaker, devised the shoulder bolt shown in Fig. 3. With this bracket the clamp is first tightened up against the shoulders of the fixing bolts and not till this is done are the nuts on the arms screwed up. This improvement made the Jobson bracket a thoroughly reliable one, and many thousands have been used in South Africa and elsewhere.

With the introduction of the tubular iron arm by the

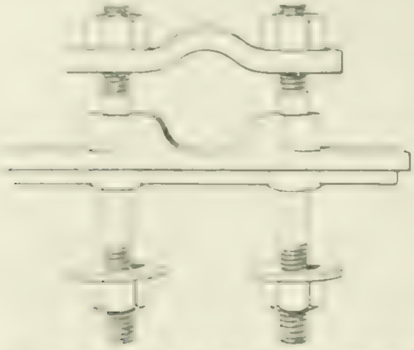


Fig. 3.—[illegible] tubular iron pole.

Post Office in England several of the Colonies quickly took it up, and with some of these it is now the standard arm. The spacing between insulators and arms is somewhat varied in the different Colonies but Fig. 4 shows used in South Africa for 4, 8 and 12 wires respectively. The 4-wire arm is 3 ft. 10 in. long and the seat is provided with shoulder bolts. The spacing at the pole is 16 in., and between the two wires on each side 12 in. They are fixed at 12 in. centres on the pole. These arms allow ample space for a lineman to get through between the wires. The 8-wire arm is 6 ft. 3 in. long and 9 in. between insulators, with 15 in. at pole. This arm is suitable for more congested heavy wire routes. The 12-wire arm is also 6 ft. 3 in. in length with 16 in. at the pole. The spacing of the wires is 4 in. between the two wires of each pair and 8 in. between the pairs. With light wires of 40 lb. bronze or 70 lb. hard-drawn copper commonly used for telephone overhead distribution purposes the author can say from many years of experience that this spacing is quite satisfactory, although it would not be recommended where snow-storms occur. The same seat is used for all the arms. It will fit poles from 1⅝ in. to 4 in. diameter and is shown in detail in E of this figure.

F of Fig. 4 shows an extension arm which fits into the end of the main arm where it is held by the first insulator bolt. This is a useful and cheap fitting for carrying one or two light wires on a short length of line, and it can be used on any tubular arm.

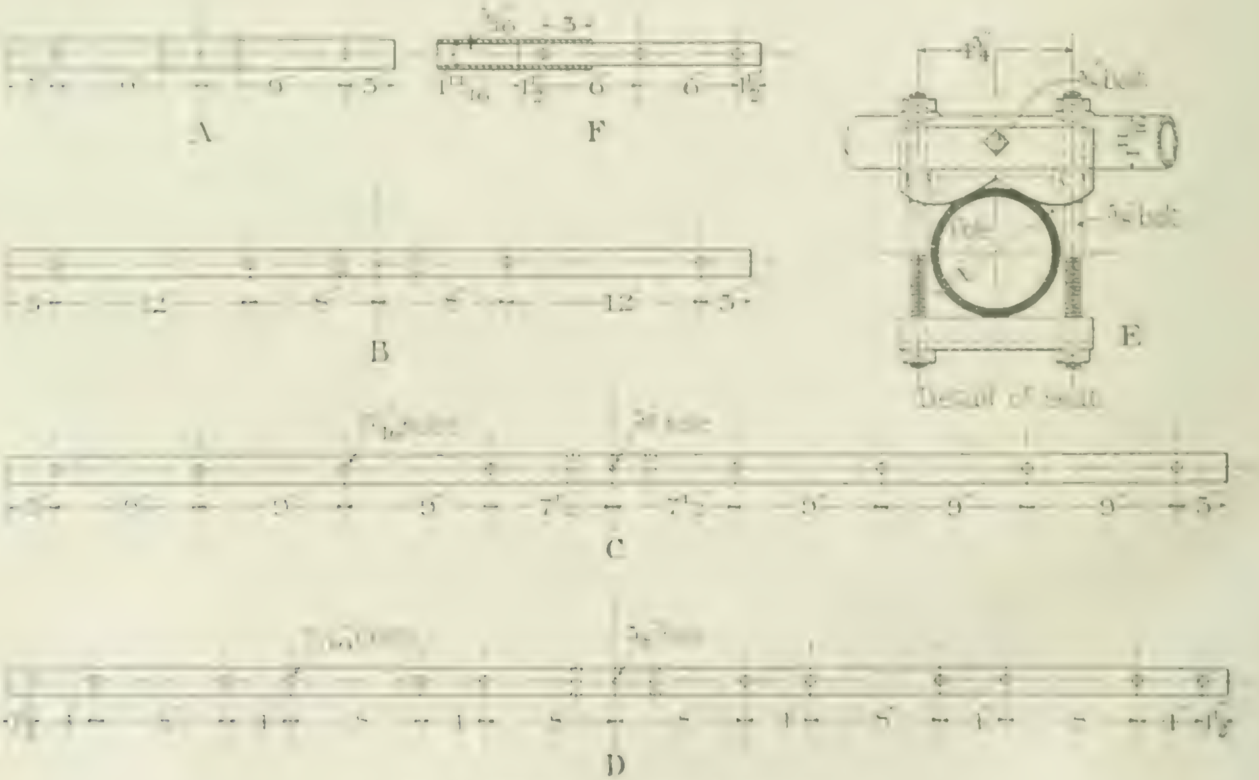


Fig. 4.—Tubular arms and insulator spacing.

A [illegible] B [illegible] C [illegible]

D 12-wire arm. E Detail of seat. F Extension arm.

and recommended spacings for the different numbers of wires [illegible]. A of this figure shows a 2-wire tubular [illegible], and B, C, and D are standard types of arms

When the author adopted tubular arms in Natal he designed and introduced a number of fittings such as tie rods, arm clippings, extensions, back braces and cage frames. A lantern slide shows five arms, each carrying twelve 40-lb. wires on 40-ft. parallel steel poles, braced together by means of tie rods. These rods are of ½ in. material galvanized with galvanized tubular distance pieces, each with a curved washer to give a flat bearing surface at each end. The arm support is fitted with an ornamental scroll in this case, but generally it was plain.

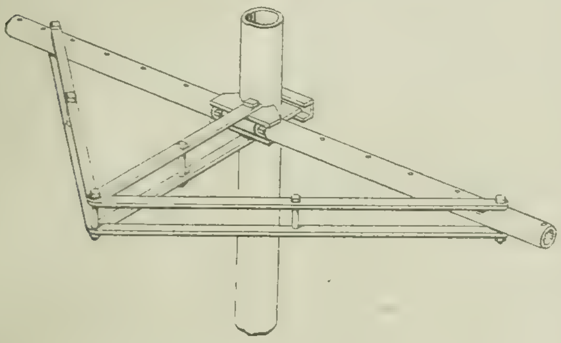


FIG. 5.—Back brace for 8 and 12-wire pole arm.

Where wires are terminated on an 8 or 12-wire arm the arm is back braced as shown in Fig. 5. The lantern slide also shows the method adopted of cross-arming the poles. The end of the pole arm is sometimes scalloped to take the cross-arm which is held in position by means of an eyebolt. The head of the eyebolt is slipped inside the main tube and is held by the first insulator spindle on it. Where the end of the pole arm is not scalloped a cross-arm holder is used. This is a piece of galvanized tube about 4½ in. in length with scalloped end as shown in the lantern slide. It is of sufficiently large internal diameter to slip over the end of the main arm and is held in position by the first insulator spindle. This spindle also passes through the eyebolt which holds the cross-arm tight in the scalloped end of the holder. Where 8 or 12-wire cross-arms are used they are back braced to the pole arm by means of two strands of 7/16 steel wire (galvanized) each with a small swivel tightener.

A four-sided tubular iron frame is used on a junction or leading-in pole carrying wires in four directions. These frames are built up in the form of a cage in which the lineman has plenty of elbow-room. A lantern slide shows a junction cage pole. Galvanized wrought-iron pole steps are much used on tubular iron poles, the practice generally being to start them from a position on the pole which can be reached from a 15 ft. ladder. From this point they are placed about 12 in. apart up the pole.

Tubular arms are made of different diameters and thicknesses of iron, but the sizes most commonly used are all 1–11/16 in. diameter by Nos. 7, 9, and 12 S.W.G. thick. They are always galvanized. Table 2 shows the results of tests kindly carried out for the author a few months ago by Messrs. Bullers, Ltd., of one arm of each of these sizes and, for comparison, one oak arm. The tubular arms were 46 in. long and the oak arm 48 in. These tests show that the No. 9 gauge tube is sufficiently strong for all practical purposes. Where heavy wires are terminated, either a stronger tube 2 in. in diameter by 5/16 in. thick or two tubes braced together should be used. Where wood arms are used they conform generally to Post Office practice in regard both to dimensions and to spacing.

If line construction is good the maintenance costs will be low and the great advantage of freedom from faults is gained. Loss of time to telegraphists, delays to telegrams, and annoyance to subscribers to telephone systems which result from interruption to wires are reduced to a minimum if the constructional work is of the best. Probably in no other class of engineering is the success of a work dependent upon factors of such low values mechanically as in telegraph and telephone engineering. A telegraph line may be 1,000 miles in length and its good working depend not only upon a thin wire having a breaking

TABLE 2.

Tests of Tubular Arms and Oak Arm.

Type of Arm	Weight	Test Weight	Set	Test Weight	Set	Test Weight	Set	Test Weight	Set	Test Weight	Set	Test Weight	Set	Remarks
	lb.	cwt.	in.	cwt.	in.	cwt.	in.	cwt.	in.	cwt.	in.	cwt.	in.	
Tubular iron, No. 7 S.W.G.	11	12½	nil	14½	1/16	16½	3/16	18½	⅜	19½	9/16	20½	¾	At 16½ cwt. the ⅝ in. seat bolts were bent. This continued to 20½ cwt., when they were badly bent and seat broke
Ditto, No. 9 S.W.G.	9	,,	,,	,,	3/16	,,	⅜	,,	½	,,	¾	,,	1⅛	In addition to the Set the tube was slightly twisted
Ditto, No. 12 S.W.G.	7·4	6½	1/16	8½	3/16	9½	⅝	10½	1	Not carried further				
Oak arm, 2½ in. sq.	11·9	12½	Fixing bolts bent			16½	Bolts badly bent			20½	Arm broke			The arm was badly twisted after 12½ cwt., but it came back practically straight when load was taken off

[illegible] and connections spread over its entire [illegible] Good materials, properly standardized for the different [illegible] the greatest importance. They may cost more initially but they pay in the end. The appearance of a line counts for nothing with some engineers; it is sufficient if passable telegraph signals or telephonic speech can be got through. But in all other branches of engineering, in bridge designing, [illegible] given to the appearance of the structure and money is spent on it. Why should the telegraph and telephone engineer be exceptional in this respect? If overhead lines are necessary in towns and suburbs from the point of view of economy, they should be so constructed as to be of neat appearance and in keeping with their surroundings as far as possible.

Double-shed white porcelain insulators of Post Office types are generally used in these Colonies and in South Africa. On the farmers' lines in South Africa and on some lines in British East Africa a small single-shed porcelain cup is used. It is quite a satisfactory light line insulator for use where the climate is dry. The spindles and cupholders used with these cups are generally of the standard types adopted by the British Engineering Standards Committee, although for light conductors single and double **J** and also **U** cupholders of lighter patterns are used. For leading-in purposes the Purves-Sinnott pot-head insulator is now much used in the single and double groove and side knob patterns in which it is made.

Bright's shackles are practically obsolete as in England, but they are still used here and there in spite of the large and direct surface they offer for leakage.

Black insulators of the large P.O. pattern made from a bituminous composition have been given a trial in several of the Colonies but they are not highly spoken of. The chief value claimed for them is that they are not so conspicuous as white insulators and therefore less likely to suffer from stone-throwing.

Glass insulators so much used in the United States and Canada, where the climate is dry, are not used to any extent in the Crown Colonies and not at all in South Africa. The inferior insulation of glass as compared with porcelain has been against its adoption. Some insulation tests of porcelain and glass insulators of the same size and shape, carried out for the author recently, gave an average of 50,000 megohms for the former and 3,500 for the latter. Both types [illegible] in water for 72 hours and tested [illegible] much affected by changes of temperature and are liable to fly to pieces even when these changes are comparatively slow. In India where glass insulators were tried they had to be abandoned because of this weakness. Where they are used on iron spindles a cushion of wood [illegible] are tougher and when used in the [illegible] sulators are fixed to the spindles by a non-elastic cement they are liable to be shattered during rapid changes of temperature. Porcelain insulators of Continental make have been used in some of the Colonies but they are extremely brittle, and it is no uncommon thing for the internal threads to be completely broken away by the swaying of the line wire after the insulators have been in use a few months. The insulation of a line is a matter of the first importance. The best insulator gives the best service, and the author is prepared to say that no insulators made are to be compared either for insulation, strength, or general serviceableness with the British Post Office standard porcelain types as made in England.

In some Colonies porcelain insulators having a groove across the top for the line wire are used. The method of binding in is not so convenient or reliable, and if a binder gives way there is a risk of the line wire falling on the outside of the cup and causing damage to traffic below. Where the top groove is not used to carry the line wire, as is frequently the case, there is no object in providing it, as it only adds to the cost of the cup.

Canada.—The arms generally used are of British Columbia fir. A 6-wire arm used by the Grand Trunk System is 7 ft. long by 4¾ in. by 3¾ in. The insulators are spaced 18 in. apart at the pole, and 15 in. between the insulators on each side of the pole, the end holes being 3 in. from the end of the arm. The spacing of the arms is 22 in. The arms used by the Canadian Pacific Company are 6 ft., 7 ft. 6 in., and 8 ft. for 4, 6, and 8 wires respectively, the end holes being 4 in. from the ends of the arm in each case. The spacing between arms is 24 in. The Great North-Western Company's arms are somewhat similar but the arm spacing is 20 in.

On telephone lines 6 and 10-wire arms are used, but the 10-wire is the general standard. The spacing is usually 12 in. between cups, with 18 in. at the pole, and the arms are generally spaced 24 in. apart, although 22 in. is used by some administrations.

All arms are supported by two galvanized braces. Double cross-arms fixed in the same plane on the opposite sides of the pole and bolted together by means of shoulder bolts are much used on terminal poles. These arms are usually further strengthened with back braces. Wood side blocks or brackets, screwed at the top to take the insulator and screwed to the pole, are often used where only a few wires are erected.

Both porcelain and glass insulators are used on both telegraph and telephone lines; but, owing to the wonderful dryness of the climate, glass is found to give sufficient insulation in most localities and is largely used, mainly in the single-shed form. Where high insulation is required on both telephone and telegraph circuits, as on long-distance lines and in wet districts, porcelain is used. The insulators are usually held on wood pins, screwed with a large thread to take a corresponding thread in the insulator. This pin has a tapering shank which fits rigidly into the [illegible] with iron washer and nut at the arm end and with a wood thimble on the top end to take the insulator. Fig. 6 is a typical illustration of pole-line construction in Canada.

Australia.—Wood arms and single iron brackets are used on both wood and iron poles. The arms are got from timber from one or other of the great variety of eucalyptus trees which are plentiful in the country. They are usually of 3 in. square section with the edges chamfered. The standard lengths are:—

42 in. for	4 wires with	9 in. spacing.
52 ,,	4 ,,	14 ,,
52 ,,	6 ,,	7 ,,
78 ,,	8 ,,	9 ,,
80 ,,	10 ,,	7 ,,
96 ,,	10 ,,	9 ,,

The spacing at the pole is 18 in. in all cases, and the distance from the end spindle hole to the end of the arm is 3 in. The arms are fixed at 14-in. centres on the poles. Wood poles are slotted to a depth of $1\frac{1}{2}$ in. to take the arms, and the latter are fixed by means of $\frac{1}{2}$-in. bolts each with a square washer $\frac{1}{8}$ in. thick under both head and nut. Wood arms are used on rail poles.

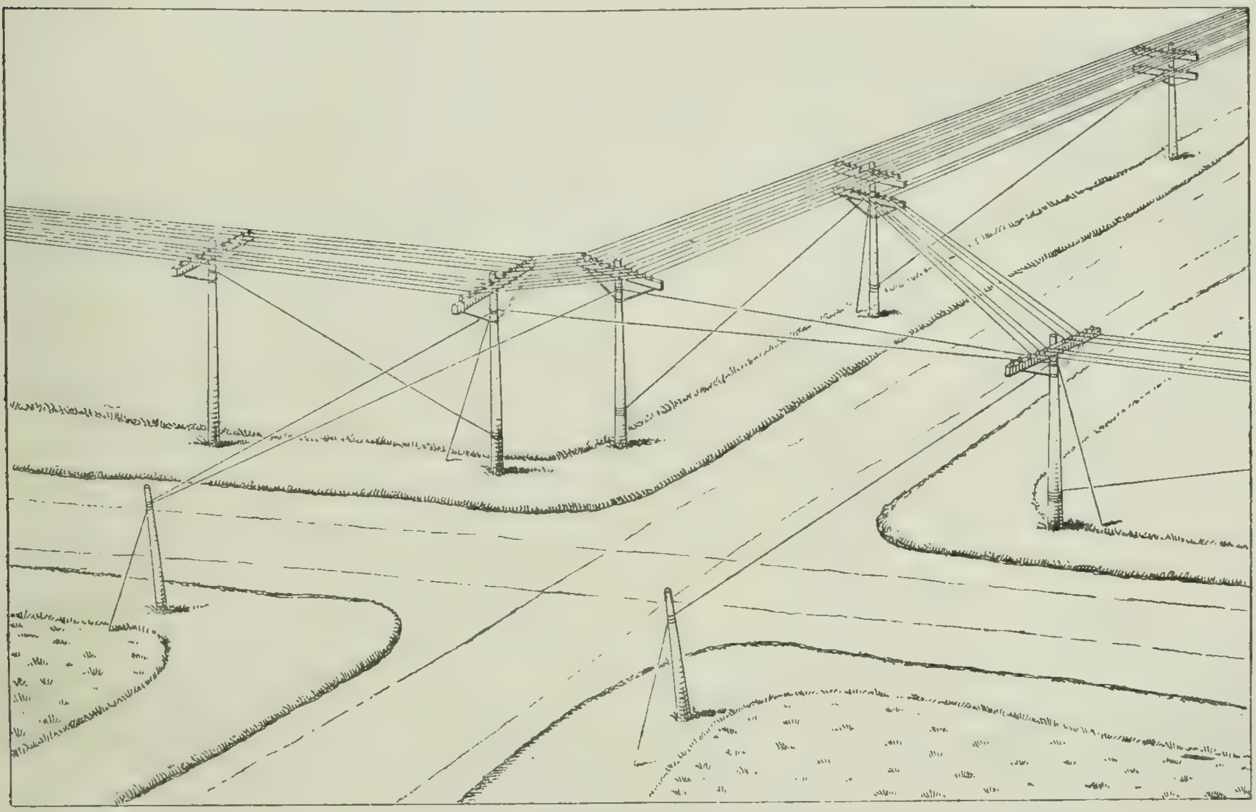
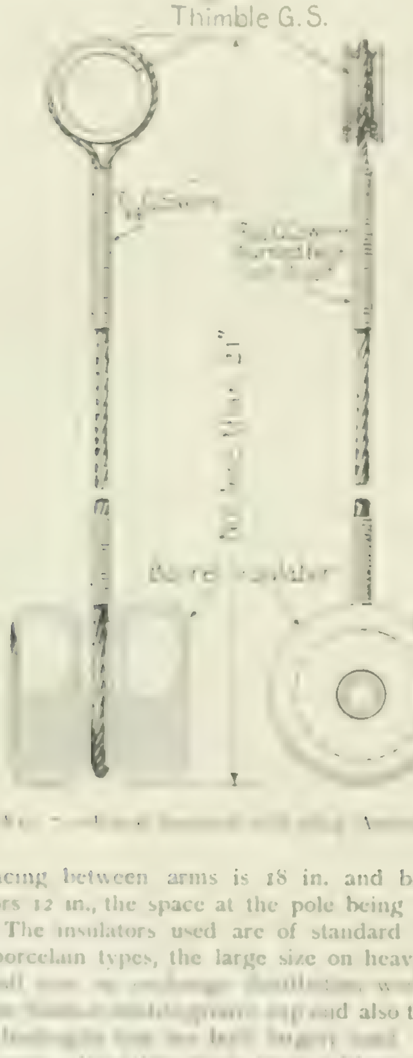


FIG. 6.—Pole-line construction, Canada.

The standard insulators used are of porcelain or stoneware of double-shed type and made in two sizes. They are threaded internally and are usually carried on wood pins similarly threaded, although iron spindles with lead-screw tops are also used. The wood pins are made to fit tightly into the wood arms. Where there is a possibility of the wire lifting the pins out of the arm or bracket a piece of 200 lb. galvanized iron wire is passed through a hole in the shank of the pin and the ends twisted together. Double terminal irons (or shackles, as they are called) with standard insulators and steel spindles and also U cupholders with British Post Office pattern insulators are used for terminating wires for transposition purposes. Special transposition insulators are also used.

The "cheaply constructed line" is a novel feature authorized by the Commonwealth Department. The methods to be adopted in this class of work are fully described in a set of Instructions on the subject. Such a line is only erected when the cost of a standard pole line is prohibitive, and it is erected on trees, saplings, scantlings, and fences. Owing to the low efficiency of the insulation this class of line is used almost exclusively for local telephone services. No hard-and-fast rules are laid down as to the kinds of supports to be used, but preference is given to trees and scantlings. Where saplings are used they must be not less than 12 ft. long and $3\frac{1}{2}$ in. in diameter at the top end. Scantlings must be of hard wood not less than 2 in. by 3 in. in section and 10 ft. long. Swan-neck spindles with pattern A or B insulators are the standard on straight sections of line. Where the wire is attached to a tree a sling insulator as illustrated in Fig. 7 is used. This is bound to the tree by means of a strand of four No. 14 gauge galvanized iron wires which is passed through the thimble on the sling. The line wire is passed through the hole in the barrel insulator and the tension on the wire is always in such a direction as to draw the insulator away from the tree. Similar slings 12 in. in length are used on angle poles. Where the wire is carried on fencing posts barrel insulators of the same [illegible] thereto.

[illegible] one owing to the scarcity of suitable timber for the [illegible] For [illegible] wires, as on telephone exchange distribution, the arms are spaced 12 in. apart on the poles, and the insulators are placed 9 in. apart. On heavy trunk and telegraph lines the spacing between arms is 18 in. and between the insulators 12 in., the space at the pole being 18 in. in all cases. The insulators used are of standard Post Office white porcelain types, the large size on heavy lines and [illegible] and also the Sinclair-[illegible] to roughen and the insula-[illegible]



[illegible]

Line Wire.

[illegible]—Galvanized iron wire is [illegible] 200 lb. and 400 lb. wires are still employed considerably; 200 lb. wire is also used to some extent for unimportant telephone circuits. The author knows one colony where iron wire of gauges of 60 lb., 150 lb., 300 lb., 450 lb., 600 lb., and 900 lb. are used. The local authorities may have some special purpose to serve in using the heavier gauges, but if it be to obtain higher conductivity the object would be better attained by using equivalent copper wires. This would improve the wire-carrying capacity of the pole lines and relieve them of the specially strong fittings which the heavy wires require.

For long distance telegraph lines 150 and 200 lb. copper wires are used. Practically all telephone circuits are of copper. In South Africa 70 lb., 100 lb., 150 lb., 200 lb., 300 lb., and 400 lb. gauges are used according to the grade of service required. The telephone trunk wires are generally erected on the twist, and on main lines and as a matter of economy both telegraph and telephone circuits are erected on the same poles. In cases where separate pole lines are erected for telephone circuits the wires are transposed on U cupholders.

The 70 lb. wire is used for local distribution on telephone exchange systems, and for this service it is in the author's opinion a useful and adequate wire. In some directions 40 lb. bronze wire is used, and while this has the advantage of strength and lightness where a large number of wires has to be erected on the same pole line it has the great disadvantage of low conductivity. In present-day practice open wire distribution is usually restricted to a comparatively small number of wires, so that the advantages of using the small bronze wire have disappeared. As any or all circuits on a telephone exchange may require long-distance connection it is desirable to keep the resistance of the subscribers' loops as low as possible, and 70 lb. copper is a satisfactory wire for this purpose.

Bronze wire usually 150 lb. per mile is employed in some colonies for long spans, but not largely, and copper clad steel wire has also been used to a slight extent. In two colonies where this latter wire has been tried it has quickly broken down owing to moisture penetrating the copper, probably through defects caused in the handling, and causing corrosion of the steel core. Where it is erected near the sea the thin coating of copper is soon eaten away and the life of the wire is very short indeed.

In situations where the insulation of open wires may be lowered from any cause, hard-drawn copper and bronze wire with a special insulation to a Post Office specification is sometimes used. This insulation consists of impregnated paper, cotton lapped and braided, the braiding being impregnated with a weatherproof composition the basis of which is red lead. This compound is impervious to moisture and its waterproof properties appear to improve with exposure to the air.

The Britannia joint is commonly used for jointing both iron and copper wires, but here and there McIntyre sleeves of both oval and twin tube type have been introduced. The author has all along favoured the wire joint, as with native workmen there is less risk with it. In inexpert hands the sleeve is liable to be badly twisted and the wire damaged. On the other hand, with the sleeve the soldering iron is dispensed with, and this is certainly a great advantage in a country where the work is in skilled hands.

The practice as to terminating line wires varies. That favoured by the author was to terminate, on both sides of a road or railway crossing, at acute angle poles; also every half mile on heavy routes, and every mile on light routes, all terminating points being securely stayed.

The usual British Post Office method of binding is adopted, copper tapes and binders being generally used with copper line wires of gauges from 100 lb. upwards, and No. 16 iron wire with iron line wires.

Earth plates of both galvanized iron and copper are used. The former costs about half the latter and serves the purpose equally well. Care should be taken to have plates of the same material at both ends of the wire. In Canada galvanized iron rods, which are driven well into the ground, are largely used.

Canada.—Copper and iron wire are both used largely on both telegraph and telephone systems. The Great North-Western Company use 210 lb. copper for the principal telegraph circuits, for others they use Nos. 6, 8, and 9 iron. The Canadian Pacific Company's standards are 210 lb. copper for long-distance telegraphs and No. 8 iron on other lines. On their Montreal–Vancouver line they have a 300 lb. copper conductor. The Grand Trunk use iron wire of Nos. 6, 8, and 9 gauges, and copper of 210 lb. gauge. They also use copper-clad steel wire weighing 245 lb. per mile on short sections in the mountains where the tensile strength of the copper is not sufficient to withstand the severe strain of the heavy wet snow and ice which accumulate on the wires there.

The Telephone Administrations generally use No. 12 iron for their open exchange lines and on unimportant rural lines, while copper of different gauges to meet the requirements of the services is used on the important lines. The rural companies generally use No. 12 iron.

The open telephone circuits in Canada are transposed. The system of transposition is based on that of the American Bell Telephone and Telegraph Company and is worked out in a very thorough manner. On the shorter circuits two-piece glass transposition insulators on the same pin are used, while on the longer circuits two insulators of either glass or porcelain are employed, a special bracket being used to carry the second insulator which comes directly under the first. Phantom telephone circuits superimposed on physical circuits are largely used and special transpositions are arranged in these cases.

McIntyre sleeves are employed generally for making joints. On copper wires copper sleeves, and on iron wires steel sleeves, and also tinned copper sleeves, are used.

As a rule the line wires are bound to the insulators by a length of wire of the same gauge as the line wire. It is taken round the neck of the cup, one end is passed over and the other under the line wire, and each end is given five complete long tight wraps around the line wire.

Farmers' lines on fences.—There are a few lines of this character in Canada. The fences generally consist of three separate strands of barbed wire on wood posts, the top strand being 15 to 20 in. from the next. The top wire is used for the line and it is not usually insulated in any way but merely stapled to the posts. The earth is used for the return. In dry weather no great amount of leakage takes place owing to the extreme dryness of the atmosphere, and fairly satisfactory talking is possible over short distances; but in wet weather the speech-transmission value of such lines is very poor. In a few instances the line wire is insulated on porcelain knobs. At creeks and road crossings the line wire is raised on poles. These lines are not permitted to be joined up to public exchanges.

Australia.—For main trunk telephone circuits copper wire 300 and 400 lb. per mile, and for minor trunk circuits which connect with the main trunk system 100 and 200 lb. per mile, is used. For other minor trunk lines and also for telegraph circuits, other than those on which fast speed Wheatstone is employed, 200 and 400 lb. galvanized iron wire is used. For the high-speed circuits copper wire is provided. Galvanized iron wire suffers very little from corrosion except when erected on the sea-coast. Phosphor bronze wire is used for subscribers' circuits on telephone exchange systems, so also is copper wire of 50 lb. and 70 lb. gauges. All joints are made by means of McIntyre or other approved type of sleeve. The use of vices, draw tongs, or grips, with roughened edges for straining the wires is not allowed. The standard British Post Office method of binding in is followed.

New Zealand.—Copper, iron, and bronze line wire is used. Copper wire of 100 lb., 150 lb., 200 lb., 300 lb., and 400 lb. is employed generally for telephone circuits of importance, and also for long telegraph circuits. Iron wire of 150 lb., 200 lb., and 400 lb. has been much used in the past and is still being erected for both telegraph and telephone purposes, but it is being less used than formerly. 200 lb. iron wire is much used for medium-length telegraph and telephone circuits where copper is considered too costly. Bronze wire of 40 lb. gauge is used on exchange distribution lines. The McIntyre sleeve is not used, all joints being of the "Britannia" standard type.

Fence wires are often used by the farmers for telephone purposes as in Canada.

TELEGRAPH SYSTEMS.

Crown Colonies.—In the Crown Colonies Post Office standard apparatus is in general use, and the circuits are to Post Office diagrams. Single needle, single and double-current Morse, double-current duplex and quadruplex are employed in the different Colonies. The Cardew vibrator is also used a good deal, in some cases superimposed on Morse lines, and also in place of the Morse on lines that suffer chronically from low insulation.

In British East Africa and Uganda, Wheatstone automatic has been introduced with Gell keyboard, and ordinary mechanical perforators.

The Vyles polarized sounder is replacing the sounder and relay, and is also being adopted with condensers on Central battery omnibus circuits. The standard practice on these circuits is to use a voltage of 80 with a feed resistance, non-inductive, of 1,000 ohms between the battery and the line. The sounders are wound to 2,000 ohms and the condenser is of 4 mfd. capacity. On a line of 150 lb. copper, 120 miles in length, the author found working was improved by introducing sufficient non-inductive resistance into the line tapping at each station to make the resistances of the tappings at all stations uniform. Where primary cells are used, the practice is to use a 2,000 ohms feed resistance.

At Colombo, Ceylon, the Baudot system has been installed on a circuit 800 miles in length, connecting with Madras. There is usually one repeater in the circuit, but [illegible] The [illegible] entially from Post Office practice in [illegible] ers as well as receivers are motor driven. [illegible] was experienced at the start owing to the storage batteries, which were already in use for other [illegible] 18 ampere-hours. The trouble was overcome by the [illegible] the battery, so that only one motor was run off the one lot of cells. With this arrangement there was no further trouble.

This system was introduced to fit in with standard practice in India. The native Morse operators quickly picked up the new alphabet and became expert in manipulating the instruments. The double set installed in the first place was soon afterwards duplexed satisfactorily. This experience should be of value to other Administrations whose traffic is on the increase. The Morse is undoubtedly better suited to native operators than the more delicately constructed type-printing apparatus, and it will continue to hold its own on ordinary lines and even on lines on which the traffic is sufficient to require a Morse duplex to carry it. But for heavier traffic one or other of the type-printing multiplex systems, of which there are several now on the market, will be found to give better results than either the Morse quadruplex or the Wheatstone.

In 1910 the British Post Office designed a secondary cell equipment on cheaper lines than that which embodies the charging cabinet with rotary switches, referred to later, and in which the charging board is so arranged that the different sections of the battery are charged in turn and while they are at work. No spare cells are provided, but if a section of the battery breaks down or has to be disconnected for any purpose the charging machine can be joined up in place of the disconnected set. The Chief Engineer of the Federated Malay States is installing plants of this character at Kuala Lumpur and at Ipoh. The voltages available will be 24 for locals, 40, 80, and 120 positive and negative for lines. The cell adopted is of the 45 ampere-hour Hart type. They will be charged direct from a petrol-driven generator at Ipoh, and off a motor-generator at Kuala Lumpur. In this equipment the main distributing cabinet is dispensed with, and a cabinet combining the functions of this and the instrument table distributing [illegible] the charging board and the combination cabinet, the [illegible] Line test cabinets of switch spring type equipped for [illegible] returns" strips, are being installed with this equipment.

[illegible] saving that may result from the substitution. The [illegible] ly common with primary cells; [illegible] cells [illegible] available for charging, the adoption of this system is worth considering.

Leclanché porous-pot form cells are much used on ordinary line and local circuits. In some directions weird types of Daniell and gravity cells are still used, notwithstanding the practice of the British Post Office in this respect, referred to later. With some engineers the old reputation of the Daniell for heavy work and constancy of current remains, and in the same way the Leclanché is still erroneously regarded by many as suitable only for light intermittent work, and the prejudice against it for heavy work dies hard.

The lightning discharger chiefly used on telegraph lines is the Post Office carbon disc with mica disc separator. The large double-plate discharger is also used in some Colonies.

South Africa.—In South Africa Post Office standard apparatus is also in general use. Double-current simplex, duplex, quadruplex, Wheatstone automatic, and Creed systems are in operation. Single needles with tapper keys are used on omnibus circuits connecting with railway stations in the Natal Province. For this class of circuit they are probably more suitable than any other type of instrument. They require no adjustment, and respond to signals of varying strength within wide limits. In the larger offices the double-plate sounder takes the place of the single needle. The Vyles polarized sounder is replacing the relay and sounder, and it is also being adopted on central battery omnibus circuits, and on concentrator systems. The author regards this system as one of the greatest developments in telegraphy in recent years. It has the centralized battery feature of the closed-circuit system without the waste of current that takes place with the latter, while under the charge and discharge process of operation it has the positive action of a double-current system. There should be a large field for the application of this system on the many unimportant omnibus circuits that run out from centres in the Dominions and Colonies.

The duplex and quadruplex systems are employed between centres according to traffic requirements. One of the longest quadruplex lines is that between Durban and Johannesburg, about 350 miles by line, and this works quite satisfactorily without a repeater. Trouble used to be experienced on the B side with the old form of repeating sounder, but this disappeared when the Post Office condenser system was substituted. The A side of this circuit is sometimes repeated at Johannesburg to the Stock Exchange there, so as to give direct communication with Durban during Stock Exchange hours. In other directions, and on circuits of greater length, full quadruplex repeaters are employed.

The Wheatstone automatic has been in use between the main centres for many years, and the Creed apparatus has been introduced more recently. The decision to adopt this latter system followed an investigation by the Engineer-in-Chief of South Africa of the various heavy traffic systems in use in Europe and America, and for the conditions prevailing in South Africa and the system of traffic circulation proposed it is admirably suited. Wheatstone apparatus was already in use at all the principal centres, so that it was an easy matter to add the Creed outfit. Long distances separate the chief towns, and in the event of a line breakdown the work can be punched up at each end ready for passage through the transmitters once communication is restored. Another point of value is that if the special apparatus should fail the stations can fall back on ordinary Wheatstone working. The Creed circuits are worked duplex, and high-speed duplex repeaters are employed on them where necessary. One of the longest of these circuits is that between Cape Town and Johannesburg, about 1,000 miles, and this has two repeaters on it. The latest type of sounder silencer, that recently brought out by the Automatic Telephone Company, on the principle suggested by Major A. C. Booth of the British Post Office, is being installed. Motor-driven transmitters have been introduced, the motors being of the type adopted by the Post Office. These motors are rather small for their work, as between their cold and hot condition they are subject to a variation of speed which is a serious disadvantage when working in conjunction with a Creed perforating receiver. This difficulty is being got over by the adoption of a larger motor. Both Gell and Kotyra keyboard perforators as well as ordinary mechanical perforators are in use.

Test boxes of U-link pattern are in general use in the smaller offices. In the larger centres test boards of Post Office standard switch spring type have been installed. For ordinary line fault-testing the "test box detector" with commutator is used, and for this purpose it is a simple and adequate instrument. For insulation-resistance testing the Evershed "Megger" is employed. High-grade vulcanized rubber-covered wires of Nos. 16, 18, and 20 S.W.G. are used for leading-in purposes at the smaller offices, and 7/22 S.W.G. for earth leads.

At the principal offices the working current is got from secondary cells with charging and distribution equipment of Post Office standard design comprising the main charging cabinet fitted with rotary switches, main distributing cabinet, and instrument-table distribution and fuse cases. As a rule the batteries are charged by motor-generators which are run off the local supply mains, and the standard voltages of 24 for local circuits, and 40, 80 and 120 positive and negative for the line circuits, are provided. On the 40 and 80-volt leads protective metal-cased resistances are inserted in the battery leads at the instruments, while on the 120-volt leads lamp resistances are provided for the same purpose.

At other stations primary cells of both bichromate and Leclanché types are used, the bichromate on duplex, quadruplex, and Wheatstone lines, and in some cases for locals; and the Leclanché of 6 block agglomerate and porous-pot forms on all other lines and locals. The principle of using Leclanché cells for all purposes up to the point where storage cells can be installed, adopted by the British Post Office after the searching investigations of Mr. Lucas, is being applied as circumstances permit. These investigations proved the great suitability for heavy work of the porous-pot type of cell when charged with a finely granulated form of depolarizing mixture: it is, besides, the cleanest and easiest cell to handle, and there is no waste of material when the cell is in disuse. The "sack" form of Leclanché cell is even more suitable than the porous-pot form where heavy currents are required, owing to its lower internal resistance. Its initial cost as compared with the porous pot is, however, against it. Dry cells are only used on telegraph work where portability is desired.

Generally the instrument rooms are equipped on up-to-date British Post Office lines. Typewriters provided by the Department are used by the operators in many of the principal instrument rooms.

Canada.—In Canadian practice minor circuits are worked single current on the closed-circuit system, the battery power being divided generally between the two terminal stations. In some cases the battery power is all at one end. On the more important lines double-current duplex and quadruplex are in use. The Morkrum printing system is also in use on several of the lines of the Canadian Pacific Company. The apparatus generally is of American make and the circuits of American design. The Morkrum printer can be worked on two methods, one by which the sending operator works a keyboard resembling a typewriter keyboard which operates directly to line, the received messages coming out on an electrically operated typewriter. By the other system the sending operator works a similar keyboard which punches holes in a continuous tape. This is afterwards fed into a mechanical transmitter which operates a typewriter of the same type as before at the other end.

There is one Wheatstone circuit between Montreal and Bamfield, B.C., which is leased by the Canadian Pacific Company to the Pacific Cable Board, but on the public lines there is no Wheatstone, Creed, Baudot, Vyles, or single-needle apparatus in use.

On many of the longer telegraph circuits, repeaters are employed. The longest lines and the number of repeaters on them are as follows:—

Company	Line		Distance in Miles	System	Number of Repeaters
	From	To			
Canadian Pacific	Montreal	Vancouver	2,900	Duplex	2
,, ,,	,,	Winnipeg	1,400	Printer Duplex	2
Great North-Western	Toronto	,,	1,800	Duplex	2
Grand Trunk	Winnipeg	Prince Rupert	1,746	Simplex	1
,, ,,	Edmonton	,, ,,	953	,,	1

In the larger offices the line wires are connected to spring-jack switchboards of American design, and lightning arresters are fitted at the terminals of the leading-in cables. Lightning arresters are used where cables connect with aerial wires, and at intermediate offices the test [illegible] There is quite a [illegible] Generally they com- [illegible] In the [illegible] switch- [illegible] ty of contact with lighting and power wires. In the smaller offices the arresters are simply small brass discs or [illegible] switchboard.

A form of sulphate-of-copper gravity cell is in general [illegible] offices, where dynamo current is available and where the [illegible] necessary plant. The Canadian Pacific Company's practice in this respect is noteworthy. Where power is available from two different supply stations, motor-generators are employed directly on the line and local circuits. Two separate machines are provided for each voltage, one with the positive and the other with the negative earthed, and in each case a stand-by machine is installed. This is used to replace either of the two machines in the event of breakdown. This means for main line current a separate set of three machines for, say, 125 volts, another set for 200 volts, and for the longest circuits another set for 400 volts. For local circuits machines giving 25 volts are used and resistance is inserted where necessary to make all local circuits uniform.

Where power is available from one supply station only, [illegible] cells are used, which are charged either direct from the main power leads or through the medium of a motor-generator. Where a motor-generator is used a stand-by machine is only provided where the office is located at some point where it is impossible to supply another machine, in the event of breakdown, before the storage battery would be discharged. With secondary cells both negative and positive batteries are installed, and stand-by batteries of 50 per cent the value of the batteries [illegible] negative, the stand-by batteries consist of 100 cells, and these are charged while the other banks of cells are in operation. This is done through a switching system developed by the staff of the company. With the storage batteries current is tapped off at different voltages so that the actual current required for circuits of different lengths is obtained.

Other companies install a complete duplicate equipment in the case both of storage batteries and of direct motor-[illegible]ation. The voltages employed are notably [illegible] with British practice.

[illegible]

[illegible] operators use typewriters, which they supply [illegible]

[illegible] Morse duplex and quadruplex are [illegible] rly Morse apparatus would [illegible] The introduction of either the [illegible] Creed apparatus was introduced between the Eastern and Western States in 1913 and has been in regular use for the past two years. The arrangement is shown in Fig. 8. Repeater stations are installed at the points dotted between Perth and Adelaide. Standard duplex repeaters are used.

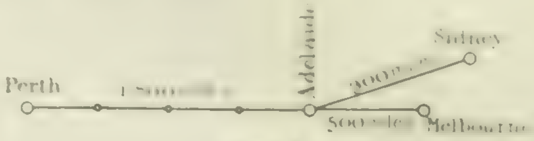


Fig. 8.

A printer and perforating receiver are installed at Adelaide. The system suits the Commonwealth traffic conditions fairly well. The maintenance costs of the apparatus are, however, found to be high, and the liability to error is considerable unless constant and expert attention is given. Each evening the Perth–Adelaide circuit is extended to Melbourne with a repeater at Adelaide. This is worked duplex and is the longest telegraph circuit in regular use. It works satisfactorily and for Press work is considered to be the most economical one possible as regards staff.

There are a few central-battery telegraph circuits in use fitted with Vyles polarized sounders.

Secondary cell plant has been installed at the chief telegraph offices, and similar installations have recently been provided at country offices where the conditions have been fonnd to warrant this being done.

Primary cells of Meidinger, Gravity, and Carporous types are in use, but the British Post Office type of Leclanché cell has recently been adopted.

All the principal circuits are equipped with typewriters, which are now provided by the Department. Hitherto the telegraphists had to supply their own machines. "Touch typists" are being trained with excellent results to transcribe Morse signals from Wheatstone tape for delivery to the public. Some of the typists have attained a speed of from 50 to 60 messages per hour.

A reorganization of the circulation of traffic from small offices has recently been made. Where formerly a number of small offices situated at great distances from the chief office of a State, worked direct with the Chief Office on one wire, they are now subdivided and connected on short lines with distributing centres which have fast direct communication with the Chief Office. This involves an extra transmission, but the experience is that the traffic is handled more rapidly and congestion is reduced to a minimum.

New Zealand.—Single-current Morse, both open and closed circuit, Morse duplex and quadruplex are the principal systems in use and the apparatus is generally of British Post Office type. Single needles have never been used, and the Wheatstone automatic was discarded some [illegible] with two quadruple sets at Wellington, which will connect [illegible] church. It is considered that this system will solve the traffic problems of the Dominion better than any of the other type-printing systems.

The longest telegraph circuit is that between Wellington and Dunedin, about 530 miles, including a section of submarine cable 40 miles in length. Quadruplex repeaters are used freely, and they are forked to meet the traffic requirements. Vyles polarized sounders have not been introduced on ordinary circuits, but they are employed on quadruplex repeaters instead of relays in a good many cases. For closed-circuit single-current working the battery power is usually divided between the two terminal stations, but it is sometimes distributed over the intermediate offices as well. The energy for the working of the telegraph circuits is obtained from primary cells of Callaud, Bichromate, Gordon, and Leclanché types. Secondary cells are employed in the larger offices for local batteries, but where these are not installed, Leclanché cells are very largely used. The Callaud, and Gordon cells are used for closed-circuit working, and the bichromate cells on the "B" side of the quadruplex sets. Complete central-battery secondary-cell plant has not so far been introduced. The telephone is largely used for the transmission of telegrams, on similar lines to those described under South Africa, and by its use the most remote places are brought into touch with the general system of the country.

Typewriters are used a good deal by the operators in the principal offices. These are generally provided by the Department, but in some cases the men provide their own machines, the Department paying them so much a month for their use.

TELEPHONE SYSTEMS.

Crown Colonies.—Throughout the Crown Colonies, and also in South Africa, the natives, who form the large majority of the inhabitants, are not sufficiently educated, or concerned in commercial pursuits either to appreciate the value of the telephone or to use it. Development statistics do not usually make allowance for this, and consequently the telephone development in these countries does not compare favourably with that of European countries. If the natives are left out, the percentage of telephones to the population will in most cases not be lower than the average in Europe.

In almost all these Colonies the telephones are in the hands of the Government. On the smaller islands of the West Indies the simple magneto system, still worked in some cases with single-wire circuits, is invariably employed, the distribution being by means of open wires.

At Georgetown, British Guiana, there is a magneto exchange equipped with multiple boards with electrically-restoring line signals for 600 lines. Both calling and clearing are by magneto.

In Trinidad the telephones are in the hands of a private company. Their principal exchange, at Port of Spain, has a central-battery manual multiple board equipped for 1,200 subscribers, with a separate magneto trunk section. The distribution is by means of underground cable in the centre of the town, but otherwise by open wires. The climate is very hot and damp and great difficulty is experienced in keeping up the insulation of the board and lines to a suitable standard for central-battery working. Some of the longer lines on this exchange suffer so badly in this respect that they have been converted to magneto working.

At Suva, Fiji, a multiple magneto board on the "ring through" system is about to be installed. This will have an ultimate capacity of 1,200. A trunk section, a calculagraph section, and also a party line section for two party circuits are also being provided. The line signal is a plug restoring drop indicator, and the clearing signal a circular star-type galvanoscope indicator.

The author is aware that there are objections to the adoption of this system in a large exchange, but he is of opinion that for exchanges in countries where the commercial conditions are not so pressing as in large centres the "ring through" has its advantages. A subscriber does not perhaps provide a special attendant for his telephone, and if he is busy when his bell rings he may not be able to answer immediately. With the "ring through" system, the calling subscriber does the ringing, and if prompt attention is not given, a second, and further rings can be given without disturbing the operator, and the calling subscriber knows that his inability to get through is not due to any remissness of the operator, but to inattention at the called subscriber's end. When the conversation is finished, both subscribers depress their "ring off" buttons. This method of clearing is also criticized, but from years of experience of "ring through" exchanges, the author can say that while one subscriber may forget to "ring off" it very rarely indeed happens that both forget, and the pressing of either button operates the clearing signal.

At Colombo, Ceylon, a magneto lamp-signalling multiple board is in use, equipped for 1,400 subscribers with trunk and calculagraph sections. The magneto is used for both calling and ringing off, the cord circuit having an impedance coil across it operating a single supervisory lamp signal.

At Hong-Kong and Singapore, the local systems are owned by a private company. At both places magneto lamp-signalling multiple boards with automatic supervisory lamp signals are in use. The ultimate capacity in each case is 5,000. The main cables from the exchange are underground with overhead dry-core cable distribution to open wires. The hand micro-telephone is exclusively used on subscribers' sets.

In the Federated Malay States, magneto lamp-signalling multiple boards with double automatic supervisory signals are being installed at Ipoh and Kuala Lumpur, while at other exchanges in the country magneto boards with plug restoring line signals, and double-lamp supervisory signals have been introduced. This system is fully described in Mr. Llewellyn Preece's paper already referred to.

British East Africa and Uganda have several small exchanges of magneto type with plug restoring line signals, and galvanoscope clearing-indicators operated by relays in bridge across the cords.

There are no automatic exchanges in any of the Crown Colonies. Not only are insulation difficulties felt to be a bar to their introduction in the damp climates of these countries, but the need for the employment of highly skilled mechanicians to look after the plant is regarded as another obstacle.

The distribution at the larger of these exchanges is generally by means of cables from the exchange led to pole lines through distribution and protector boxes fixed to the poles. The subscriber density is so low that service by direct cable can be given but rarely. Business premises [illegible] have been laid in glazed earthenware troughing filled [illegible]

The underground cable distribution is sometimes arranged by means of cast iron boxes of Post Office types in the manholes, but the method most generally employed now is that of lead branching joints. These joints do not afford the same means of re-arranging the redistribution as do the boxes, but where the development can be fairly accurately estimated, it is better to run the circuits through in a permanent manner to their respective terminations. Cable boxes are very often a source of weakness and trouble owing to slack work on the part of the maintenance staff who have access to them.

Where the distribution is by means of armoured cable [illegible] protection and to preserve the continuity of the armouring. Where aerial lead-covered dry-core cable is used it is supported in the usual way on steel suspender wires. A cable suspender best suited for a tropical climate is made with a loop of three-ply tarred marline, which is attached to the suspender wire by a suitable galvanized steel hook. Raw-hide suspenders quickly deteriorate in a hot, damp climate, and zinc suspenders are too rigid for the [illegible] They are apt to grip the cable too tightly and set up crystallization and fracture of the [illegible]

For small exchanges the author prefers the underground armoured cable. It can be used with complete safety. The upkeep is practically nil, all the work of erecting suspender wires and the heavy stresses they bring upon the poles are obviated. There are cases, however, where the great convenience of the overhead cable outweighs all other considerations, as where there are obstructions to an underground route, or where a pole line to carry the [illegible]

[illegible] of cables in a building usually follows Post Office practice, the cables being connected to distribution cases by means of a link of enamel and cotton-covered lead-sheathed cable made airtight with bees-wax. This class of cable is also used between the underground cables and the main frames in exchanges. Similar cable, [illegible]

[illegible] tropical Colonies, but it is liable to break down owing to [illegible]

[illegible] dry-core cable which is sealed up with compound when the paper-covered wires have been soldered on to their tabs. The other compartment is fitted with ordinary carbon dischargers and fuses. The dry-core cable is wiped on to a gland at the bottom end of the box which gives access to the back compartment, while the leads to the open wires are usually taken through a hole in the top of the box and through a pipe which screws into it, to the top of the pole. Another form of double-compartment box fitted with vacuum dischargers and fuses and a single-compartment box with ordinary carbons and fuses are also used.

The leading-out cables from the pole boxes are single-pair enamel and cotton-covered and lead-sheathed. At the open ends they are taken through pot-head insulators of the Purves and Sinnot type.

Where underground cables are connected to pole lines it is usual to take out not more than 25 pairs at any distribution point. This permits of comparatively light and inexpensive pole-line construction.

The main frames at the larger exchanges are fitted with ordinary carbon dischargers, fuses, and heat coils. Various types of protectors are provided at subscribers' stations, but the two chiefly used are the combined carbon, fuse, and heat coil, and the vacuum with heat coil.

Special measures are taken in the manufacture of all apparatus for use in the hot humid climate of the tropical Colonies to keep up the insulation of all electrical parts. Teak-wood is always used, and screws are of non-corrodible material. Iron or steel mounts are zinc plated, and precautions are taken as far as possible to prevent insects getting inside instruments. For coil windings of large-gauge plain enamelled wire is the rule, but it is sometimes given a single lapping of silk which is impregnated with bees-wax. The silk in this case is certainly a mechanical protection for the enamel and is of value in this respect. Owing to the difficulty of properly enamelling wire of gauges smaller than about 30 S.W.G., small-gauge coil windings are given a single silk covering and the coil is impregnated with a high-quality insulating varnish in a vacuum chamber. This impregnating process makes the coil quite moisture-proof.

All switchboard wiring and cabling is done with enamel and silk and cotton-covered wire.

No. 2 Leclanché cells of both porous pot and sack types are used on the magneto instruments.

South Africa.—In South Africa the number of telephones per 100 of the population not including natives is about three. The telephone services throughout the country are under the Government with the exception of the Durban exchange, which is owned and worked by the municipality. Every town and village of any importance has its exchange, and a large trunk system has been developed. At present the longest connections in regular use are about 500 miles in length. A speech efficiency equal to 30 miles of standard cable is aimed at, and intercommunication is given to all stations that come within this limit. Loading coils have not yet been introduced, but they will be employed when the time arrives to consider the longer trunk lines between the Cape and Transvaal main centres.

The Durban exchange has a central-battery manual [illegible] bution in the busy area is by dry-core underground cable taken direct into buildings where possible, and otherwise to distribution boxes of Western Electric type on buildings in alleys, and on poles. Outlying sections of the town and the suburbs are fed by main cables sub-divided through lead branching joints and distributed in a similar manner or by open wires on poles, the trolley wire poles of the tramway system, which also belongs to the municipality, being used for the purpose. Independent pole lines are also erected where necessary. Connection is given with other towns in Natal and in the adjacent Provinces through the Government trunk system.

At the principal Government exchanges central-battery manual boards are in use, the largest being that at Johannesburg, with an ultimate capacity of 9,000 lines. Separate sections for incoming junctions and trunks are provided. Similar exchanges of rather smaller capacity have been installed at Cape Town and Pretoria, and also at about half-a-dozen other towns on the Witwatersrand. At nearly all other towns magneto boards on the "ring through" system are employed. In some cases the boards are of the lamp-signalling and lamp-clearing types; in others drop shutters are used, and again in other exchanges indicator-jack boards are in use with mechanically restoring clearing drops.

Magneto boards with automatic clearing are in use at certain exchanges. With this system a condenser is placed in the telephone circuit of the subscribers' instrument. When two subscribers are through, potential is on both subscribers' lines through the supervisory relays. When the telephones are hung up the loops are closed, the supervisory relays are energized, and the clearing signals operated. This differs from the automatic clearing system of the Federated Malay States in so far that in this case the short-circuiting of the loop from any cause gives a false clear, while in the other system a similar fault would prevent the clearing signal being given at all. In both cases it would be unlikely that both sides of the through circuit would be faulty at the same time, and the operation of one relay or the other would attract the attention of the operator. The hand micro-telephone is used throughout on subscribers' instruments.

Telegraph circuits are superimposed on telephone wires where it is advantageous to do so, and phantom telephone circuits are obtained wherever possible. The telephone is much used for public telegrams between outlying stations and central transmitting offices. In such cases the instrument is usually in the charge of the local postmaster, often a storekeeper. Such offices are also used as trunk-call offices. On lines of this character it is not unusual for several offices to be in bridge on the same pair of wires, the calling being done by a code system of ringing. Magneto telephones are used, and silence cabinets of standard types are provided.

The installing of an experimental automatic exchange was decided upon some time ago, but the war has interfered with this project, as it has done with the telephone development generally in the country.

Both wet and dry cells are used on magneto telephones. The author always used wet cells in Natal, as he found them more reliable and economical than dry cells. A dry cell is no longer efficient when it becomes really dry, and in a hot, dry climate the moisture which keeps the cell active is liable to evaporate quickly and leave the cell useless long before the elements are used up.

The underground cables and distribution methods vary in the different Provinces in accordance with the practice in vogue prior to the union, but the work of co-ordinating the methods to one standard has now made great headway. In present-day practice underground cables having 10 lb. conductors are in use. Heavier conductors are employed where required, also composite cables having large conductors for long-distance circuits. Cast iron and earthenware conduits are employed in the older construction, while in the later work American fibre ducts have been introduced. Underground armoured, and aerial dry-core cables are also much used. Lead branching joints in manholes are in general use on underground distribution. The joints are made solid with compound which is forced in under pressure. Recently the "Matthews" pot joint largely used in the United States has been brought in for trial on both underground and aerial cable work.

Distribution is carried out both by underground direct cable, and on the block system from high poles by means of both dry-core cable and open wires. In both cases the internal distribution is through lead-covered cables to distribution frames or cases, and thence to the subscribers' sets. Cables are also led to open wires through pole distribution and protector boxes. Both cast-iron double-compartment boxes and wood boxes are used fitted with ordinary carbon dischargers and fuses. With the former the cable is wiped on to the union sleeve of the box and the wires terminated in the air-tight side of the box. Where wood boxes are used the dry-core cable is usually pot-headed, with rubber wires which connect with the protector box. Open-wire distribution is on somewhat similar lines to those already described as in use in the Crown Colonies, but the American method of leading in to a subscriber's station by means of rubber-covered drop or bridle wires secured to a porcelain knob at the point where the wires enter the building is being introduced.

The main frames at the telephone exchanges are generally fitted with ordinary carbons, fuses, and heat coils, and subscribers' instruments connected with open wires are similarly protected.

The local telephone development in some parts of South Africa has been quite phenomenal, especially in the mining districts of the Rand. In older and more settled localities the development studies are based on a 15 years' estimate for ducts, and ultimate capacities of switchboards, and a 5 years' estimate for underground cables, local distribution and exchange equipment.

The practice of drying out paper cables by means of dry-air pumps fitted with desiccators is followed in some of the Crown Colonies, but the tendency now is to adopt the method of jointing described later under Canadian practice. In South Africa portable dry-air pumps are provided for use only when a definite fault appears.

Canada.—The Bell Company have central-battery manual systems in their larger exchanges, and in exchanges below 500 or 600 lines they use magneto boards. They have no automatic exchanges.

The practice of the Manitoba Government Department is on similar lines. Their magneto boards are fitted with plug-restoring line signals of the eyeball type.

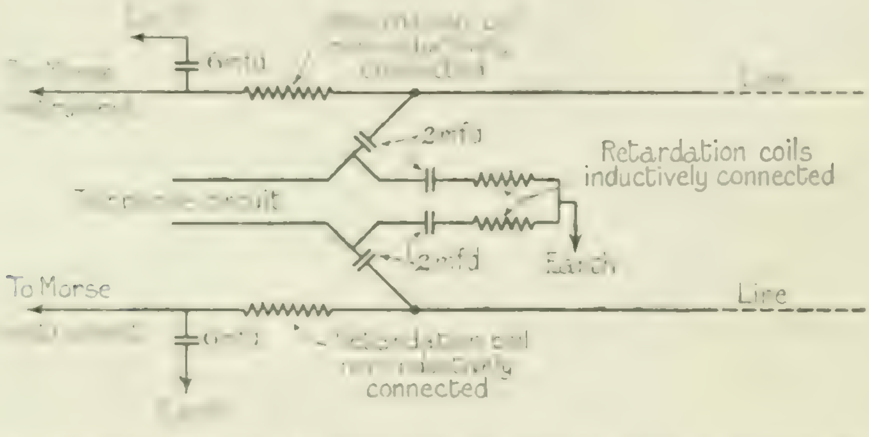
In Alberta and Saskatchewan the Government exchanges [illegible] automatic system as [illegible] The latter [illegible] are connected. It is spread over four exchanges and an area of roughly [illegible] exchanges in these two provinces are magneto except two central-battery manual [illegible]

[illegible] subscribers' magneto instruments [illegible]

[illegible] generally followed. Underground branch cables are taken into the blocks from the main underground cables and are terminated through rubber-covered wire potheads in large wooden weather-proof terminal boxes fitted with fuses. From these boxes the circuits are distributed through the blocks by aerial dry-core cables which are terminated in cantop terminal boxes, whence they were led to the subscribers' premises. The company are working towards an all-cable distribution in their exchange areas. Vitrified clay ducts of 2, 3, 4, and 6-multiple type, with manholes of brick or concrete suitably placed, are used on their main routes with single ducts for the branches. Other administrations' methods are on similar lines and in some cases fibre ducts are employed. Another method is to take the [illegible] and to terminate it in a distributing box fitted with fuses. In another case the aerial cables are taken direct from the underground cable and distributed without fuses. The [illegible] used both with and without protectors to [illegible]

[illegible] ons vary [illegible] American prac- [illegible] exposed to [illegible] contact with lighting or power wires. To come under this classification they must therefore be exposed, as on aerial lines, for a distance of over half-a-mile. Carbon dischargers are fitted at these stations. Exposed stations cover all others whether served wholly or in part by aerial cable, open wires, or twisted-pair insulated conductors. Carbon dischargers and fuses are fitted at these stations. In all cases the protectors are placed in as accessible a place as possible inside the building near the point of entrance of the wires.

Leading-in is generally done by means of twisted-pair drop wires from the cable terminal, or open wires, to the point of entrance. They are sometimes taken through bridle rings on buildings spaced 4 ft. apart on horizontal runs, and 8 ft. apart in vertical runs. To keep the wires taut in the rings they are tied with short pieces of discarded insulated wire. In cases where fuses are provided, the latest practice is to connect them outside the building and without any mounting, the drop wires and the wires leading inside being tied off on porcelain knobs and the fuses connected between the open ends of the wires. The carbon discharger is placed just inside as before. The wires are taken inside through holes drilled in the walls, the holes being fitted with tubes of "circular loom" or, in some instances, porcelain. The "circular loom" is a rigid tube of spiralled paper treated with rubber compound lapped with india-rubber prepared tape and braided with [illegible] powdered mica mixed with it. It is made in different diameters and can be cut into lengths as required.



[illegible]

The drop wires, or bridle wires as they are often called, are of 18 S.W.G. copper insulated with a rubber compound, cotton-braided, and impregnated with a weather-proof compound. This wire is used in single, double, and triple form, and the wires when twisted together are distinguished by raised tracer threads in the braiding. Where two wires are twisted together, one has a single raised thread, while with the triple-strand one has one raised thread, another has two raised threads, and the third is plain. [illegible] used in single, double, and triple form, the distinguishing [illegible]

Superimposed telegraph circuits which are usually leased to the telegraph companies are arranged on both "simplex" and "composite" systems. The "simplex" is the well-known system which gives one Morse circuit superimposed on one telephone pair by means of repeating coils. The "composite" gives two Morse earthed circuits, which can be worked either single or duplex, and one metallic telephone circuit on one pair of wires. The theoretical connections of a terminal composite set are given in Fig. 9. The condensers and retardation coils on the Morse arms prevent the telephone currents from passing through these arms and they also so flatten the telegraph currents that the "thump" which would otherwise be heard in the telephone is reduced to a minimum. The condensers and retardation coils connected in shunt with earth off the telephone circuit have the effect of reducing the momentary telegraph currents that pass from one Morse circuit to the other through the telephone circuit. These earthed branches have a high impedance to telephone currents and a low impedance to telegraph currents, so that the latter are largely shunted to earth. The condensers in these branches prevent the earths on the retardation coils from interfering with the local telephone calling-signals. For telephone signalling over circuits fitted with "composite" apparatus a special ringing set is provided. The same ringing set is sometimes used on the "simplex" system. Both systems can be adapted to the working of intermediate stations. The telephone transmission loss due to the introduction of a repeating coil at each end of a telephone circuit on the "simplex" system is equal to about one mile of standard cable, while the loss on a circuit equipped with a "composite" set at each end is equal to about ¾ mile of cable.

The minimum speech efficiency on the long-distance circuits varies under the different administrations, but it ranges from 30 to 36 miles of standard cable. The general dryness of the climate contributes to a high standard being attained.

Long-distance lines are equipped with lightning discharges on the poles at suitable intervals, and where these wires are taken into an office or testing station it is a common practice to place the dischargers one or more poles away on each side of the office. The "Chapman" discharger shown in Fig. 10 is a type much used for this purpose.

On main distribution frames carbon dischargers and heat coils are used by the Bell Company, but carbons and fuses are more generally provided by other administrations.

Branching joints on underground cables are of the lead Y-type and all joints both straight and branching are treated with paraffin wax. In making a straight joint the lead sheath is removed from the ends of the cable for a distance equal to the length of the lead sleeve. The core is bound tightly with strips of muslin at the end of each cable sheath, the binding being packed close to the sheath so as to prevent the wires being cut by the edge of the sheath. The exposed conductors are thoroughly "boiled out" by pouring hot paraffin wax over them with a ladle until all traces of moisture are removed and the binding is thoroughly saturated with paraffin. Enough paraffin enters the sheath to form a seal which protects the cable against moisture while the joint is being made. The temperature of the paraffin is above that of boiling water, but it must not be high enough to scorch or make brittle the paper insulation. In "boiling out" the cable it is the rule to work from the cable sheath towards the ends of the conductors. The jointing of the wires is done in the usual way, the joints being distributed along the whole length of the splice. The whole of the jointed wires are again "boiled out" until all traces of moisture have been removed. The splice is then wrapped with strips of muslin and compressed until the lead sleeve will just slip over the splice. The splice is again "boiled out," and this operation is again repeated after the final wrapping is completed, the drying out being continued until air bubbles cease to appear on the splice. The lead sleeve is slipped over before the splice has had time to cool and wiped on to the cable sheath at each end.

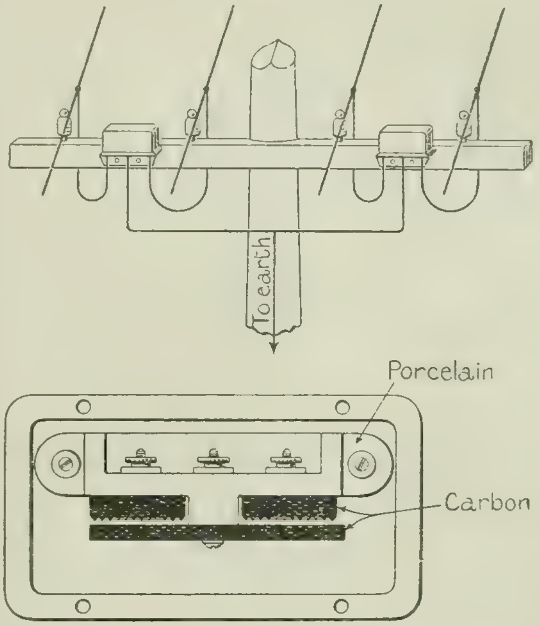


FIG. 10.—Chapman lightning arrester (Canada).

The splice on a dry-core cable is undoubtedly its weakest point, but this form of joint when carefully made is so reliable that breakdowns are of very rare occurrence. It is in almost general use in the United States.

There is no through communication yet between the Eastern and Western shores of Canada. There is a break of 600 miles between Fort William and Kenora in which there is no telephone line at all, and the Rocky Mountains form another break between Alberta and British Columbia. The longest lines regularly in use in Canadian territory are those between Montreal and Windsor, and Montreal and North Bay, distances of about 600 miles. Loading coils are in use on both open-wire and underground sections of the long-distance circuits. Communication is given with a large number of places in the United States through the trunk lines of that country, the longest distances being Montreal to San Francisco, 3,800 miles, and Toronto to San Francisco, 3,200 miles. (Communication has since been arranged between Montreal and Vancouver, via the

[illegible]

The telephone development of Canada is higher than that in any of the other Dominions or Colonies. For the whole of the Dominion the average number of telephones per 100 of the population is [illegible]. In British Columbia the average is as high as [illegible] while in Manitoba and Alberta the figures are [illegible] respectively.

Australia.—Probably no country in the world has taken up automatic telephony so whole-heartedly as the Commonwealth. In 1912 the Chief Electrical Engineer personally investigated the systems then in use in America and Europe. His report, dated [illegible] October 1912, deals in a very thorough manner with the comparison which may be made between manual and automatic systems. In his review of the question of the suitability of automatic systems for the conditions existing in Australia he attached great weight to the difficulty of obtaining adequately-trained and disciplined operators for manually-operated exchanges, but it is not clear to what extent this difficulty influenced the decision to adopt automatics. In comparing the semi-automatic with the full-automatic he contended that the view that it is desirable to interpose an operator to control the series of operations that have to be made, and to check and correct failures when these occur, is wrong and he declared himself emphatically in favour of the full-automatic for Australia. Since then important headway has been made, full-automatic equipment has been installed in 10 exchanges, the largest of which is Perth with over 3,000 subscribers. Six other exchanges are in course of construction or approved, tenders have been invited for a further 18, and 14 others are under consideration. The exchanges so far opened are all equipped with the Strowger system, but both the Siemens and the Western Electric Company's systems are to be tried.

Both central-battery and magneto exchanges are in use. Distribution from all the larger exchanges is effected by means of underground cables. On very small exchanges open-wire distribution is adopted. A good deal of aerial cable of both the dry-core and rubber types is installed, but its use is rigidly prescribed, as its erection is not economical in the Commonwealth where the estimated 5 years' capacity is 50 pairs or over. Rubber-covered paper-core aerial cable has been used in certain of the States, but it has not proved satisfactory. On exchange distribution it is the practice to serve subscribers' premises by underground cable wherever this is warranted. Where the service cable contains less than 10 pairs it is terminated in a joint made solid with insulating compound, with leads on the subscribers' side consisting of silk and cotton, or [illegible] lead-covered cable. Where the service contains more than 10 pairs and less than 100 they are terminated on a distribution case. Where the number is over 100 they are terminated on a cross-connecting frame. Where the cables are led to distribution cases or frames they are terminated with a short length of lead-covered silk and cotton-insulated cable which is made airtight with bees-wax. Where cables are led to exposed wires the distribution lines are connected through a pole distribution-box several types of which are in use. [illegible] well is the "Cook" dome type. This is cylindrical in shape with a compartment for the cable. It is fitted with carbon arresters and 3-ampere fuses. Open distribution wires on central-battery networks are terminated on Post Office pattern pot-head insulators and are led in by means of lead-covered enamel and cotton-insulated twin cable. In magneto cables twisted-pair india-rubber-covered wire is much used for leading in where the length of lead is short. Where the distance is over 12 yards the method of leading in in central-battery areas may be adopted. The substation end of a span of twisted-pair wire is terminated on a button insulator secured to a small galvanized steel bracket. Where the ends of two twisted pairs may be terminated at one point the bracket may be equipped with two insulators. Bridle rings are used for carrying twisted-pair distributing wire on the outer walls of buildings. They are spaced not more than 4 ft. apart on horizontal runs and 8 ft. apart on vertical runs. The protective apparatus, where such is fitted, is placed in as accessible a position as possible and as close to the leading-in point as is convenient. For protection against lightning, strong currents, and sneak currents the lines are divided into two classes, i.e. "exposed" and "unexposed." Generally speaking the former includes all lines, open and covered, which may come into contact directly or indirectly with heavy-current wires, while the "unexposed" lines are those composed exclusively of underground or submarine cable, or of open wire or aerial cable which cannot possibly get into contact with wires carrying heavy currents. The practice laid down for the provision of protective apparatus is well thought out. At junction points between exposed and unexposed cables and wires, fuses and arresters are generally installed. Outside protection against lightning is not usually adopted, apart from exchange distribution lines, unless in the opinion of the local engineer such is warranted.

The Post Office method of jointing and drying out dry-core cables is followed.

On subscribers' instruments on both central-battery and magneto exchanges control keys of a Yale pattern are supplied for a small fee when required.

Selective 4-party line services are provided on the central-battery exchanges and code-ringing party lines on the others, and on lines in country districts.

Both wet and dry cells are in use on subscribers' instruments, but the Post Office Leclanché cell with powdered depolarizer is now being adopted.

Development studies are based on a 12 to 15 years' estimate for conduits, and a 5 years' estimate for cables and exchange equipment.

There is a fairly extensive trunk system within the individual States, but the only capital cities as yet connected are Melbourne–Sydney (505 miles) and Melbourne–Adelaide ($487\frac{1}{2}$ miles). On both these circuits Morse duplex is superimposed and worked regularly. Proposals have been put forward for a Sydney–Brisbane trunk circuit. The trunk wires are carried on the same poles as the telegraph lines. On certain of the main lines the trunks are twisted, but on other main lines and on country lines the transposition system is in use, and this system is likely to be continued. Loading coils have not yet been introduced into the Commonwealth. The percentage of telephones to the population at the end of last year was 2·721.

New Zealand.—New Zealand was very early in the field in establishing telephone exchanges at its principal centres, and many of the exchanges installed between 20 and 30 years ago are still in operation. The boards are mostly of the old Western Electric magneto type with branching multiple and with drop-shutter line and ring-off indicators. There are also other makes of magneto boards in use. Many of the larger exchanges have become quite inadequate for present requirements, and the question of substituting more efficient systems has been before the authorities for some years past. The introduction of the central-battery manual system was contemplated, and three Western Electric central-battery exchanges were installed, but the administration hesitated to introduce this system generally in view of the development of automatic systems. In 1911 the Chief Electrician of the Department was deputed to inquire into the various systems in use in America and Europe, and as a result of very exhaustive investigations he recommended the adoption of automatic exchanges for several of the principal towns. Experiments were carried out with several automatic systems available at the time, and the Western Electric Company's full-automatic system was decided upon as being the best calculated to meet the varied services of the Dominion. Contracts were entered into with this Company for exchanges for the Wellington and Auckland telephone areas, and for separate single exchange installations for Masterton, Hamilton, Oamaru, and Blenheim. Masterton and Hamilton are being equipped for 800 lines, and Oamaru and Blenheim for 600 lines. The ultimate capacity of each of these exchanges is the same, viz. 1,800 subscribers' lines, and 200 junction lines for special services. At each exchange a separate manual toll board is being provided to take all special services such as trunk (toll) lines to distant exchanges, farmers' lines, which are magneto, and some of which are earthed lines, pay station lines, both magneto and central battery, etc. The cord circuits on the toll board are of special interest inasmuch as they give connection between all the different kinds of line circuits on the exchange without the aid of auxiliary switching keys, and each cord circuit affords complete supervision on all connections made.

At Wellington the system will have three main exchanges with immediate equipment respectively for 4,000, 2,500, and 600 lines (ultimate capacities 8,000, 4,000, and 2,000 respectively). In addition three sub, or "satellite" exchanges off the largest main exchange with capacities from 200 to 600 lines are contemplated, the ultimate capacity of the whole system being 20,000 lines, and accessory junction lines. Two of the main exchanges are now being installed, and but for delays caused by the war these would have been in operation by now. At Auckland the arrangements will be on similar lines with four main exchanges, and two "satellite" exchanges, the total ultimate capacity being the same as at Wellington. Each system will have a common manual toll board situated at the principal exchange in each case. Subscribers' meters are not being installed at present, but provision is being made so that they can be put in either in part or whole at any time, and the meters when installed will register effective local calls only. A time alarm-signal is provided to indicate an earthed line, and also to show when a subscriber's line is being wrongfully held up. All exchanges are arranged for main line service, private branch exchange service, and for party line service. There are many other interesting features in the design of this system, but details of these are beyond the scope of this paper. There is every confidence that the system will adequately meet the very varied telephonic conditions of the country, and it is not too much to say that before many years have passed all the important exchanges throughout the Dominion will be "automatic." Herein lies an object lesson to countries similarly situated as to climatic and economic conditions.

The cables are laid in iron pipes or fibre conduits for distribution from the exchanges. They are led directly underground into buildings where this is warranted, but in a more general way are pot-headed and taken through pole distribution-boxes to open wires on poles. The pole boxes are of American type, and are fitted with carbon dischargers and fuses. Armoured cable is also used a good deal. Dry-core lead-sheathed aerial cable is also largely employed, but owing to high winds many faults occur in this due to crystallization of the lead, and fractures at forked joints. The tendency, therefore, is not to use this class of cable so much as formerly. These cables are suspended by means of tarred marline hangers on steel suspender wires. Dry-air plant is provided at the principal exchanges, but portable machines of British Post Office types are mostly used. Leading-in to subscribers' instruments is by means of high-grade twin twisted rubber-covered wire, braided and compounded. Carbon lightning dischargers are provided at the subscribers' instruments. These are fitted either outside or just inside the building at the point of entrance of the wires. Fuses are also fitted where there is a possibility of contact with lighting or power wires. Dry cells are used to some extent on subscribers' magneto instruments, but Leclanché No. 2 porous-pot cells are in almost general use. There is a considerable network of trunk telephone circuits. Nearly all outlying exchanges are connected with their larger centres, and some of the latter are interconnected. The longest speaking circuit is that between Wellington and Auckland, a distance of about 420 miles. This is obtained from two 400 lb. copper wires which are used for quadruplex telegraph purposes during the daytime. At night-time —after 6 p.m.—they are used as a telephone trunk circuit. The trunk wires are erected on the twist principle, and they are generally carried on the same poles as the telegraph wires. In many cases telegraph circuits are superimposed on the telephone wires, and phantom telephone circuits are also obtained. Loading coils have not so far been installed, but their introduction is under consideration. The standard of speech on trunk lines is the equivalent of 30 miles of standard cable. The number of telephones per 100 inhabitants is 4·6.

LIGHTNING DISCHARGERS AND PROTECTORS.

The methods of protecting lines and apparatus from lightning and power currents as described in the preceding section are so varied that the author thinks the subject, which is a very important one, is worthy of special consideration. In many cases the old telegraph practice of placing the main dischargers inside the building and either in or near the test boxes, in the case of telegraph wires, or [illegible] the instruments. Long insulated-wire leads through the [illegible] great extent with the development of the telephone, and to-day it is generally, although by no means everywhere, recognized that the proper place for the lightning discharger is outside the building, or if inside it should be placed as near the point of entrance of the wires as possible.

In the author's experience in Natal where most violent lightning storms occur almost daily in the summer months [illegible] and carbon-disc dischargers, with silk-covered wire on earthed metal spindles, and reels between the dischargers and the instruments, and in all cases the protectors were inside the offices and usually alongside the instruments. The instrument coils were usually saved, but often at the expense of damage to wire casing and fittings caused by the lightning bursting the rubber insulation and sometimes [illegible] set on fire and in more than one case practically burnt out by lightning being conducted into the building through wires that were fitted with dischargers which would have given efficient protection if they had been placed outside instead of some distance inside the building.

In large towns the lightning conductors on high build[illegible] static discharges and in doing so they automatically relieve the atmospheric electrical pressure, and so help to prevent the occurrence of violent discharges, but they do not by any means prevent them altogether. On the contrary it may be said in many instances they actually contribute towards them, especially in the case of highly charged clouds moving rapidly during a general atmospheric disturbance and suddenly coming within discharge range of [illegible] actually struck by lightning; they may be merely severed [illegible] disappear, deflagrated by the current, and such cases are not of rare occurrence on open country lines. The discharges the engineer has to protect himself against are those due to induction. The nearer the lightning storm is [illegible] more powerful the currents induced in the wires, but very [illegible] lightning where the open wires are over half-a-mile in length, while no doubt adequate in Canada, would not be sufficient in a country where lightning is really bad.

In Natal the author carried out a long series of experiments with the object of proving what types of protectors were best suited to the different working conditions there, and the following is the practice which he considers to be the best.

In telephone-exchange practice on a large scale, and even where the distribution is largely by means of underground cable, it is advisable to provide carbon dischargers, fuses, and heat coils on the main distribution frame which should if possible be placed in a fireproof room. With all the precautions that may be taken at the outside terminations of cables there is always a chance that through slack work or other causes the cables may be so affected by lightning discharges and power currents as to cause damage at the exchange, and the importance and value of the exchange plant are such that no risks of this nature should be taken.

Where aerial cable connects with underground cable carbons and fuses should be used at the point of junction. The heat coils at the exchange will take care of any stray currents of low value. The lead sheathings of underground cables should be efficiently earthed, and where such cables are in iron pipes they should also be bonded to the pipes as a protection against electrolytic effects from stray underground power currents. Lead sheathings of aerial cables should be earthed for the same reason and also to protect them from lightning.

Where cables connect with open wires a carbon discharger and fuse should be fitted in the distribution box. The protection from light stray currents will again be got in the heat coil at the exchange.

At subscribers' stations connected by underground cable throughout, no protectors are required, but in all other cases, i.e. whether connected by aerial cable or open wires and where protection against power circuits is necessary, carbon dischargers with fuses and heat coils should be provided and they should be placed as close as possible to the point of entrance of the leading-in wires.

In the case of a small telephone exchange where the distribution is by aerial cable the same principle applies. Where all the distribution is by means of open wires terminated on a leading-in pole, whence they are taken into the exchange by either aerial or underground cable, all wires should be protected from lightning on the leading-in pole. If fuses and heat coils are required, as in the neighbourhood of power circuits, they can either be placed in the pole box with the lightning dischargers [illegible] building. If a standard frame fitted with carbons, fuses, and heat coils is employed the carbons should remain in use as they form an extra safeguard.

[illegible] Where the cable enters the building the wires should be [illegible] station where the wires are open right up to the office they should be protected outside with either vacuum dischargers in waterproof cases or with Wurts dischargers (described in the next paragraph). If power circuits have to be provided for, fuses and heat coils which should be placed just inside the building where the wires enter should be used in addition, and the wires carried from these to the test box.

For protection at out-of-the-way offices where unreliable attendants are in charge, the carbon discharger is not always suitable. It has the drawback that with heavy discharges carbon dust is liable to be generated and deposited between the two plates of the discharger, connecting them together and so earthing the line. Such an office may be many miles away from the headquarters of the nearest lineman, and the person in charge may not have the slightest idea how to set about removing a fault if one occurs. The author has known a skilled lineman spend several days in travelling to a distant office which was cut off, only to find that lightning had earthed the line wire in the carbon discharger. At a station of this class a discharger is wanted which will give protection without earthing the line. For this purpose the Wurts discharger was found to be most reliable. The type used has three cylindrical pillars of non-arcing metal with serrated surfaces, set in a porcelain base mounted on an iron bracket. The cover is of zinc. It will take one line wire on each outside pillar, the middle pillar being connected to earth. Where one or two were required at an office they were fixed on a wooden pole arm, but where a number of wires had to be protected the dischargers were fitted in a strong weatherproof box and clamped to the pole at a suitable distance from the ground. The connecting wires from the line wires were led as straight as possible, without spirals, twists, or sharp bends, and the earth was made as short and direct and as good as possible. With all types of dischargers it is essential that the greatest care be given to these points. The insulated wires running into the office were spiralled a few turns where they left the line wires and the slight impedance thus introduced formed an effective choke to the discharge. Where dischargers of this type were employed and properly installed all other protective devices, such as fuses, spindles, and reels with fusible wires on them, were dispensed with.

This discharger is equally satisfactory on sections of line where lightning is specially troublesome, as on high, exposed tracts of country. Connected to the wires at suitable intervals they save them from damage due to heavy lightning charges flashing from the wires to the arms and poles, and they relieve the discharges at the terminal stations.

On railway signalling lines on which metallic circuits were used to minimize the effects of lightning the discharger shown in Fig. 11 was used. On these circuits working had to be carried on at all times, as any interruption resulted in the disorganization of railway traffic. This discharger is on the Lodge principle and is the most effective discharger known to the author. It is, however, very expensive, and prohibitively so for a number of wires. The Wurts discharger might have been quite adequate but it was introduced on other lines subsequently to the adoption of the Lodge discharger on these railway circuits, and the latter served the purpose so well that any risk there might have been in trying the other was never undertaken. This type of Lodge discharger is constructed with two separate series of three discharge discs and choke coils for the line wires. The central disc is earthed. The two line wires are connected to the two top discs and below each disc there is a choke coil containing a number of turns of fairly heavy wire. The main discharges take place at these discs. The two succeeding discs on each side are similarly arranged with choke coils. With these dischargers in use the signalling instruments were operated in the heaviest lightning storms and not in a single instance during several years of operation did a discharger fail in its duty. As the edges of the line discs were burnt away by the discharges, they were turned slightly round to give fresh points for discharge and it only rarely happened that a disc became so burnt as to require replacement.

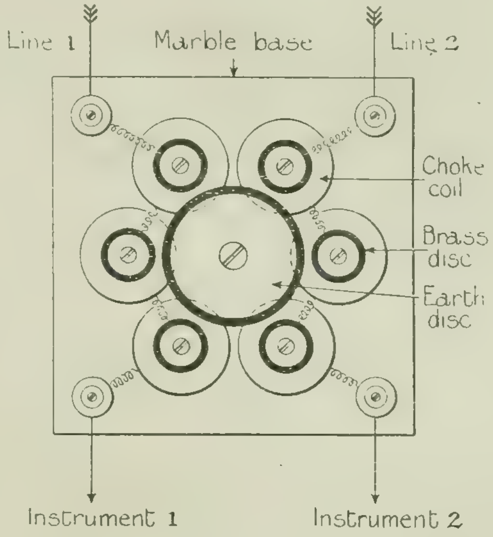


FIG. 11.—Lodge discharger, Natal pattern.

DISCUSSION BEFORE THE INSTITUTION, 14 DECEMBER, 1916.

[illegible] especially illustrates the difficulty of telegraph and telephone engineers in the colonies, both in keeping them- [illegible] and equipment. After the War we shall have to organize our national services throughout the Empire so that they may be conducted with considerably more unity than hitherto. It is very pleasing to me to hear that what assistance has been given in this way has chiefly been supplied by the engineers and by the practice of the Post Office. This has been encouraged by Post Office policy, but it has also largely been the result of the personal and individual interest of the officers of the Post Office. Before the War we were entering on large schemes for extending the research branch of the Post Office and the standardization of all equipment, and this paper shows that when we again take up those developments after the War it will be of great importance to include work for the benefit and assistance of our colonial services.

Mr. Preece **Mr. LLEWELLYN PREECE**: Colonial engineers who are miles away from this country and who have very few opportunities of getting home will be glad to read a paper like this which tells them exactly what their colleagues in other parts of the world are doing and how they are dealing with their troubles. I think one of the most interesting and most important sections of the paper is that dealing with administration. In most parts of the world the telegraphs are run by the Post Office. The chief administrator [illegible] important that all engineers should study administration as far as they can. It stands to reason that as an engineer gets higher up in his profession he becomes more and more a manager rather than an engineer, and a man who is purely an engineer and nothing more is of very little use in the higher positions. I wish to call attention to a paper read [illegible] paper there is some very interesting information about [illegible] said that when the schooner arrived at Havelock some of the poles were still growing. Immediately the schooner reached Waikouaiti the wagons commenced loading up, and within a few weeks from the time the poles were growing trees, they were carrying the telegraph wire. Owing to portions of the old road being abandoned and the inaccessibility of the line, it was decided five years ago to move some 35 miles of line passing through Naseby to Wedderburn. When dismantling this line it was found that the bulk of the poles which had been erected 38 years were still in first-class condition, and some 85 per cent of them were re-erected." I do not think that in this country, even with our best creosoted poles, we can say that many of them have been standing for 38 years.

Mr. McBerty **Mr. F. R. McBERTY**: The author has referred to the extensive and rapid conversion of the telephone systems in Canada, Australia, and New Zealand to automatic machine switching. In New Zealand in the decade following 1884 the number of telephones increased sixfold, in each of the next two decades threefold; for the six years preceding 1914 the average rate of increase was 12 per cent, for 1914 15·3 per cent, and for 1915 8·7 per cent, bringing the telephonic saturation to an average of 5 per cent and in the large cities as high as 9·5 per cent. The rapid displacement of apparatus has facilitated conversion to the modern switching methods. Within a short period contracts have been made for 30,000 lines in automatic telephone exchanges, amounting to about 55 per cent of all lines now connected, and covering all but three of the cities having more than 1,000 lines. The interest of the matter is that if the planned programme is carried out and the growth continues, the New Zealand telephonic area will be the largest in the world converted to automatic switching, and may keep its place for some years. Although the possibilities of improving service have appeared to be the main influences in bringing about the adoption of automatic switching in the Dominion and in the Commonwealth, the high and increasing wages paid to operators has been an important factor. This factor is dealt with by Mr. Hesketh in an interesting article published in June 1916 in the *Annales* [illegible]istration, in which is given the first accurate published information as to the cost of operating such systems; showing for a 5,000 line exchange (on the Strowger System) a saving of 33·5 francs per line per year, and suggesting that even larger savings may be expected.

[illegible] colonial engineers feel satisfied that the British Post Office practice is a very good standard to follow. There are a few points in the paper upon which further information [illegible] lantern slides. The author said, in describing one of the [illegible] ever have winds, or snow, or falling leaves, and whether there were any joints in the wire between the poles; [illegible]

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o.

line in this country we should certainly get frequent interruptions. I also noticed in another photograph that where the line passed along the side of a railway the stay wires were apparently stretched right across from one side of the rails to the other. Do the railway authorities approve of such a construction? Mr. Preece referred to some poles that had been in use for 38 years, and asked whether we had any poles in this country of such antiquity. I can point to some that are 40 years old, but the average age is certainly considerably less. The life of a pole in this country is not, however, as a rule determined by its death; most poles are removed after their utility has ceased, because they have to give place to larger poles or are disturbed owing to compulsory alterations, removals, and so forth. The question raised by the author as to administration, or rather what he calls the geographical versus the functional organization, is one that will come up in every administration which covers a large area, a large number of systems, and a big staff. It is really another way of saying specialization versus generalization. Obviously when the industry becomes big and involves many interests, it is necessary to specialize. The question of having to wait so long for stores from England would perhaps be overcome if the system of having a reserve stock were more extensively adopted. In England I keep £2,000,000 worth of stores always available, and upon that stock we draw for any works that we have in hand. It seems to me that an administration of even moderate size must have a stock of some kind. Our practice is to base it on one year's consumption. Reference is made in the paper to poles in Australia which are provided at joint cost by the railway and the telegraph administration. I can understand the equity of that arrangement, but how is equity provided for when subsequent wires are fitted by either party on to the same poles? We have not many iron poles in this country, as we have no white ants or bush fires or roaming elephants to provide against. That is to say, we take full advantage of the greater economy and better service obtained from wooden poles as compared with iron. The factor of safety of 4, quoted by the author, is no doubt quite good where the atmospheric conditions permit, but I would point out that with an 8 lb. pressure and an ice rope of $\frac{1}{2}$ in. radius we have five times the load to be borne as compared with merely a 17 lb. wind pressure. In connection with reinforced concrete poles, I should like to know why the experiment was made with solid as against tubular poles. Tubular poles must be much lighter, and I am of the opinion that a rectangular solid pole with the same cross-section as a tubular hollow pole would not have any additional strength, certainly not commensurate with the additional weight.

(*Communicated*): Felt washers, after several years' experience, have been abandoned, and the use of rubber washers has been reverted to, as the latter are more satisfactory in preventing insulators from unscrewing. Recent tests of Karri wood arms after 15 years' use show that they retain a very high proportion of their original strength and are still equal to our standard for British oak. The running of trunk telephone wires on the "cut and cross-over" principle has been adopted in this country with advantage from the standpoints of economy and efficiency. Black composition insulators originally came from Germany and were liable to the defects mentioned, but since the War an insulator has been made here which is stronger and more durable. Secondary batteries are so much superior to primary batteries, especially at times of peak load, when the latter are most liable to failure owing to polarization, that they should be adopted wherever practicable. The rotary switch system ensures minimum prime cost, minimum reserve batteries, and maximum uniformity in working.

Sir William Slingo.

Mr. Walker.

Mr. E. O. WALKER: The use of aluminium wire is not referred to in the paper; I should like to know to what extent it is used, if at all, for the telephone and telegraph services. I also desire to ask whether, on the very long distances mentioned, any particular spacing is arranged between the wires in order to prevent induction interferences. From my experience of dense forests I think that very heavy iron wire is the best thing to use there. I should hesitate to use hard drawn copper and bronze wire when heavy trees are constantly falling during the monsoon, since copper and bronze wires easily break; whereas if a tree falls on an iron wire, the wire elongates, and even though the wire is pinned to the ground, the circuit will work with a vibrator. This is not possible when the wire is broken. That is doubtless the reason why heavy gauges of galvanized wire have been sometimes used in particular localities.

Mr. Moir.

Mr. A. MOIR: I propose to deal more particularly with the question of cables and joints. Before we can adequately discuss any method of jointing, I think we should be in agreement as to the meaning of the terms which we employ. There are three main types of joints in telephone cables. The first is the air-space joint, in which the paper is carried right through and the joint is left quite free. The second is the boiled-out joint, in which liquid paraffin at a very high temperature is poured upon the cables when they are opened to be jointed and during the process of jointing—this is not a solid joint. In American practice a space is left under the sleeve of the joint so that, if necessary, air can be passed through. The third is the solid joint, which is filled with an insulating compound and is hermetically sealed. The author has closely followed these definitions. But when we last discussed this subject Mr. Llewellyn Preece[*] described a boiled-out joint as a solid joint, and the discussion which took place immediately afterwards was, as a result, thrown somewhat off the line. That is to say, the joint which Mr. Weightman has described to-night as a boiled-out joint Mr. Preece described in his paper as a solid joint, so that the need for being particular about the terms we use is, I think, apparent. I think we are all agreed about the solid joint. It is a joint which is usually introduced at the end of an air-space cable at the point where it enters an exchange, but the two joints about which I think there is quite a healthy difference of opinion are the boiled-out joint and the air-space joint. I hold no brief for either, but I think the air-space joint has a good many virtues that we are apt to overlook, while the boiled-out joint represents certain difficulties in application which are also sometimes not fully recognized. To apply liquid paraffin at a temperature of 350° or 400° F. to an open joint on a country road need not perhaps be a very difficult operation, and to apply it in the subways of a town is also perhaps not very difficult, but I should like to know whether the author has had any experience of the treatment of cables

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[*] *Journal I.E.E.*, 1915, vol. 53, p. 545.

[illegible] the present [illegible] of a city like London [illegible]. It seems to me that the risks to the public would be very great indeed; and if it is suggested to do this work at night I consider it to be equally dangerous to handle liquid wax near street lights. Even if these [illegible] are overcome there is the difficulty of getting the liquid [illegible] compound at a proper temperature, and also the risk to the men standing below in the crowded manhole. Those are some of the difficulties which occur to me. The author states on page 114 that where the development can be fairly accurately estimated it is better to run the circuits through in a permanent manner to their respective terminations. I entirely agree with him, because cable distribution-heads, however carefully they may be handled, are a source of risk from the maintenance point of view, and the less they are employed, to my mind, the better. When I was in Paris in 1913 I had the opportunity of examining the cable-work in that city, along with other members of the Post Office delegation who accompanied Sir William Slingo, and we found that the French were extraordinarily careful in preserving their air-space cables. They had cable distribution-heads, and cast-iron test boxes at various points, but they never allowed the paper cable to enter the boxes. A solid joint was interposed in the air-space cable before the boxes were reached. The latest practice as seen in 1913 was to provide overground chambers on the ground floor of a building, into which cables were led and connected to cast-iron air-tight test boxes, which it was understood were about to be used for cross-connecting points as well. In all these cases the paper cables were solid jointed before they reached the test boxes, extensions of silk and cotton-covered wire being used, and for that reason it seemed to me that the overground arrangement in Paris was a little elaborate. Certainly had the cables been passing an exchange they would have been solid jointed and connected to the main frame, the usual jumper wires being used to afford facilities for cross connection. In London that practice is followed successfully. Although I agree that the routing should be from the exchanges wherever possible, there are occasions when demands for tie lines within an exchange area are so numerous that cross-connection arrangements must be made, as, for example, in Whitehall, where so many of the Government offices require communication with one another. It is not possible to run separate cables from every Government office to every other Government office, and in a room in the middle of Whitehall a sort of "Clapham Junction" main frame has been introduced, with an ultimate capacity of 9,600 pairs, which enables the distribution between the various Government offices to be properly carried out without unnecessary duplication of cable. The author said, I think, that desiccating was now only carried out at the point of trouble, that is, as I understand, portable desiccators are used and are applied to the cable at the point where the insulation shows weakness. That is the practice which is being generally adopted in this country. At the outset, the practice of the National Telephone Company, and of the Post Office, was to install desiccating plant at the exchange where motive power was ever readily available. But the desiccating plant at the exchange has had a very extended and efficient range, and we found that portable desiccators, [illegible], are so efficient that the idea of providing desiccating plant at new exchanges has been therefore abandoned.

Mr. F. W. Crawter: On page [illegible] the author discusses the desirability of the electric lighting of exchanges being placed in the hands of a telegraph or telephone engineer, and he says: "Between the power requirements of telegraphy and telephony and the requirements of the various systems of lighting there is, however, a wide difference." How anybody who is familiar with such intricate apparatus as an automatic telephone exchange can complain of the complexities of an electric lighting installation I cannot understand. I think colonial engineers are to be congratulated on the life that they have obtained from the various applications of their secondary batteries under, to them, novel conditions, quite up to the average of batteries in this country, and I think that this is all the more creditable because the conditions of operation of a battery in a common battery telephone exchange is not quite on all fours with the care required by a battery in, say, an electric lighting plant, primarily because, in order to allow for extensions, the boxes in the first instance are provided large enough to contain considerably more plates than are at first installed. Consequently in order to do away with the large volume of acid which would otherwise be present if one installed, say, 7 plates only in a box capable of holding 25 plates, dummy displacement tanks are utilized to avoid having such a large volume of acid. Even so, there is not the same range of specific gravity between charge and discharge as obtains in, say, an electric lighting battery, and gravity readings, therefore, are not such a correct indication as to the condition of the cell. To deal with this point it is now becoming the practice of the British Post Office to specify within limits what the variation in gravity shall be in cases where the boxes are not filled with their complete complements of plates. The author refers also to the use of secondary batteries for telegraph work, and I think he might have put the case perhaps a little more strongly when he says that with such batteries complaints of weak signals are not often received, as every telegraph man knows that with secondary batteries the signals are much stronger than with primary batteries. With regard to the charging of secondary batteries, I consider that for small capacities it is simpler to charge direct from the mains through a resistance rather than through a motor-generator, but with larger capacities charging off the mains would be rather wasteful.

Mr. C. C. F. Monckton: I only arrived in England a week or two ago from one of the farthest colonies in the Empire, namely, Fiji, and possibly it will be of interest if I describe what we are doing there. The paper should lead, I think, to considerable standardization, but at the same time I think there are special conditions in each colony which will make variations necessary, depending more essentially on the labour and atmospheric conditions. In Fiji we are troubled a good deal with the high cost of living and expensive labour. There are three classes of labour in Fiji. For cutting down timber we employ Fijians to whom we pay 2s. a day. For other work we pay Indians, who have been for five years in the colony, 2s. a day, and we have to pay untrained white labour 12s. to 15s. a day. It will thus be seen that the labour conditions are fairly severe. We are able to get a competent lineman from New Zealand for £200 ion. a year, rising to £250 a year. In his paper the author has dealt with the question of delays in delivery; we know how difficult it is to get goods, and necessarily so at such a distance. In a place like Fiji it means making provision for about two years ahead. With regard to the question of administration, in Fiji we have a separate telegraph and telephone department. The superintendent of the telegraph department is responsible not only for the engineering side but also for sending out accounts, both telegraph accounts and telephone and wireless accounts. He is also responsible for collecting the revenue. In towns three governing factors have to be borne in mind; first, the expensive labour; secondly, the hurricanes; and thirdly, the poor house construction. In the towns in Fiji we use iron-bark poles from Australia. A few old poles of 15 years' standing are, I believe, in existence, but the existing system in Fiji was started only about six years ago. A little of the sap wood has deteriorated, but otherwise every pole that was erected six years ago is almost perfect. We have very narrow streets, and there is not much room for the poles. Balconies jut over the street, and in some cases we have to use iron brackets fixed to the houses. Then we have to contend with the poor house construction and the hurricanes. When a hurricane occurs a good many of the roofs of the houses, which are made of galvanized iron, fly off. The galvanized iron sometimes flying about 100 yards may easily cut through 60 wires. We have gradually reduced the number of overhead wires and are now putting down 13 pairs of armoured cables to get over the difficulty. These iron-bark poles are very heavy and costly, and in the country districts, where transport is more difficult, we use iron poles of tubular construction. We have recently followed wireless practice, and over a river of 440 yards' span have used 7/19 silicon bronze wire, which seems satisfactory. I have noticed one thing which may have been observed by other engineers, namely, that when we use square iron-bark poles creepers do not grow up them. I have been out in Fiji for five years; for the first four years there were practically no thunderstorms, so I took few precautions; but during the last hot season the lightning was very troublesome indeed, and I am now trying Siemens's vacuum arresters at different points along the lines. In one case of a fire last year I traced the cause to the lightning striking the galvanized iron roof, going through the woodwork of the house and then out through the telephone wire.

y. Mr. D. H. KENNEDY: In considering Canada the author, after describing the method of preparing the boiled-out joint, says: "The splice on a dry-core cable is undoubtedly its weakest point, but this form of joint when carefully made is so reliable that breakdowns are of very rare occurrence. It is in almost general use in the United States." He speaks apparently with commendation of that system. In dealing with Australia he confines himself to this remark: "The Post Office method of jointing and drying out dry-core cables is followed," and there is no comment. Some London telephone and telegraph engineers doubt whether the present type of dry joint is the best. It undoubtedly offers the facility that when trouble occurs we can turn on the dry compressed air and remove the trouble very quickly; but on the other hand the cost of desiccating, which seems to be very frequently necessary in a large city, where the joints are open air-space joints becomes very considerable. I notice that in the recent issue of Preece's "Telegraphy" a remark is made in regard to the British method of drying out joints, namely, that it is practically confined to the British Isles, and that the American system is on quite other lines. I should be glad if Mr. Weightman would give us his opinion as to the respective merits of the two systems. Mr. Kennedy.

Mr. W. AITKEN: I should like to make a few remarks regarding outside construction and exchange systems. With regard to the former, one is rather surprised to see mentioned some of the relics of the past—the "Bright" shackles, and "barrel" insulators, the latter being illustrated. Reference is made several times in the paper to "leading-in" insulators. That is very gratifying to me because, I believe, I was the first to point out the necessity for the use of leading-in insulators, in June 1896, in connection with the introduction of the permanent battery on open-wire, overhead-line work. My design of 1897 was adopted by the National Telephone Company and some hundreds of thousands of these insulators were used by that Company. The new Purves and Sinnot pattern adopted by the Post Office is a very excellent design, embodying the spirit of my original invention. I should like to ask the author what his experience has been in regard to the bringing of the two wires of a circuit to two separate knobs on one pattern of this insulator. A fundamental function of the original leading-in insulator was to prevent leakage of the current to earth when the covering of the leading-in wire was wet. It seems to me that on the Purves and Sinnot pattern there is leakage from wire to wire when the two wires are on the same insulator, when the surface is dirty and wet. I should like to know if in practice this is sufficient to affect transmission. I rather dislike the "ring-through" system being introduced at Suva, Fiji. The ring-through system is good in certain conditions, but I do not believe it is good practice to give the public any responsible operating to do after it has attained connection, other than to replace the receiver. To "call" by turning a crank, or by rotating a disc in an automatic system is all right, but having attained his connection the caller should give the clearing signal, or restore all apparatus to normal by replacing the receiver. In the case of Suva he is asked to depress a key. In the first ring-through system that I designed, in 1896, I recommended that ringing-through should be with the receiver in the hand, so that automatic clearing was obtained on replacing the receiver. The system that I designed in 1898, which was adopted by the National Telephone Company to replace the call-wire system, cleared by depressing a key after conversation, but I believe the inferior system was adopted. All that is required to give automatic clearing is that the switchhook should earth one or both lines, and a very simple device on the generator to short-circuit the receiver when ringing. The objection made was that a subscriber would never learn to ring with the receiver in the hand, but that argument does not appeal to me. The author makes a reference to "train despatching" in Canada, which might be amplified. That is a most important application of telephone operating in Canada and the United States. As members are probably aware, that is a "party line" with from 20 to 50 railway Mr. Aitken.

Mr. [illegible] [illegible] signals and the like connected. At one end of the circuit or at an intermediate point a despatcher is located who controls by telephone the whole of the traffic on a section of a railway line. The despatcher has a series of automatic impulse-sending keys, one for each station, so that he can call any station, whether another station is on the circuit or not. Every station has immediate telephone access to the despatcher by lifting the receiver. There are several systems—the "Gill" was the one I saw in use in Montreal. The Western Electric Company and other firms also have systems on the market. I believe one or two British railway companies are using a modification of the Western Electric Company's system on their railway services, but not for train despatching.

Mr. Gill. Mr. F. Gill: I propose to confine my remarks to two or three points. First, the author refers to American organization and he uses the expression "engineering (or plant as it is termed)." It is not correct to assume that the American organization merely changes the name of the engineer into that of the plant engineer. It is true that part of the organization is often divided into the three parts, but above that is the chief engineer and he deals with the recommendations from the plant and traffic superintendents. Next I want to refer to the question of insulation. The author mentioned trouble that occurred at Port of Spain. I should like to ask him whether he can give any analysis of the trouble there. I have come to the conclusion that it is really a question of making a careful analysis. A case I have in mind is one in a warm country, and there we [illegible] made a number of repeated tests on the plant without any precautionary measures being taken. The humidity at 8 a.m. ranged from about 85 to 95 per cent; the average humidity on the days of the test was 90 per cent. The rainfall on one day of the test was 4⅝ in. and on some of the other days of the test was 1 in. The percentage of lines during these repeated tests which were not then fit for central battery working varied between [illegible] and 8 per cent. We think we know where the trouble is and how to get over it, and do not think there will be difficulty in installing a central battery. May I now refer briefly to the subject of joints. I investigated this subject some years ago, and my opinion is very strong that the boiled-out joint is far superior to the dry joint. It is true that if there is dry air plant we can repair the faults, but it is also true that if the fault is a very bad one there is nothing to do but take the cable out. If that is correct, dry air is a method which will repair small faults. The next question is: Where do the faults occur? And the answer is, in the joints. If a boiled-out joint is taken and deliberately abused, we shall find that the boiled-out joint will stand up to much more bad usage than will a dry joint, in my opinion. Dry air plant involves a considerable capital expenditure and I believe that the boiled-out joint is more economical than the other. Of course, as Mr. Moir said, precautions must be [illegible] sufficient importance to turn the scale in the other direction.

It seems to me that the author has not devoted sufficient attention in the paper to economic questions, and I take as [illegible] On page [illegible] the author says that for distribution from the underground cable to the [illegible] copper wire, and he recommends [illegible] very desirable to keep the resistance low. That seems to me to be wrong. I do not think it is a question of keeping the line resistance as low as possible, but of working to predetermined standards of transmission. Suppose that in designing a system we want our subscribers' lines to have a resistance between 200 and 300 ohms. Consider the case of a large number of subscribers who are within about half a mile of the exchange. If we put in a 10 lb. cable the resistance will be about 100 ohms, and there will be 100 ohms to spare. If a 6½ lb. cable is used there will be about 42 ohms to spare, and if a 5 lb. cable, about 12 ohms to spare, and it is economical to use that resistance. A main requirement for distributing wire at the end of the cable, particularly if it is for covered distribution, is mechanical strength. We can get that by using iron wire, and we can get it within the limiting resistance. I think it will be found that the difference in price paid for a 70 lb. copper wire if a 60 lb. iron wire can be used will be more than that payable if it is desired to effect the same saving in transmission by applying the remedy in some other part of the circuit. The figures below are based on pre-war prices, and with the prices that prevail at the present moment one does not wish anything to go out from the Institution which would prevent the cheaper metal from being used in the proper place.

Assumptions {
Length of distribution 0·125 mile of circuit
Waste [illegible] per cent
Price—Copper £81 per ton
Bronze £102 5s. [illegible]
Copper-clad steel,
[illegible] £[illegible] [illegible]
Iron £[illegible] [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	lb	lb	[illegible]	[illegible]	[illegible]	S M	S M	S M
Copper	70	210	18	33	651	0·04	0·10	0·14
Bronze	45	220	11·6	16	531	0·08	0·30	0·38
Copper-clad steel	42	306	11	13·7	413	0·10	0·41	0·51
Iron	60	215	13·4	20	117	0·14	0·60	0·74

Major Booth. Major A. C. Booth: The information in this paper detailing the type of work done in the colonies gives us an opportunity of "seeing ourselves as others see us." The conditions of climate, staff, labour, etc., are so very different from those we experience in the home service that one is not surprised at variations from our methods; but it is gratifying to know that these methods are, in the main, satisfactory, and that the information and advice given to our colonial colleagues is so very well appreciated. Passing to the branch of the paper that, just at present, interests me most, viz. machine telegraphs, I must call attention to the remark on page 112 regarding the Creed, which reads as follows: "The maintenance costs of the apparatus are, however, found to be high, and the liability to error is considerable, unless constant and expert attention is given." This information is of real importance to all concerned with main-line traffic, and I should like to know the experience of other users on this particular point. The first cost of the Creed apparatus is in my opinion far too high as compared with the cost of other apparatus giving approximately the same output and economy. If, also, the maintenance costs are equally disadvantageous to users, then it is obvious that preference will be given to those systems which do not suffer from such drawbacks. Turning now to page 110, some misconception might arise from the statement in regard to Baudot apparatus in use in Ceylon and India differing essentially from Post Office practice, in that the distributors as well as the receivers are motor driven. The difference is merely in the method of driving and is a small matter ; whereas from the telegraphic point of view there is no difference whatever. The installations in India are mainly, if not all of them, worked on the simplex method with one or more channels in each direction, similar to the sets worked between London and Paris until recently ; while the Ceylon installation is worked either simplex, like the sets in India, or as duplex on exactly the same method as the duplex Baudot sets in this country. One of the greatest advantages claimed for the original simplex Baudot system was its capability of providing simultaneous communication in both directions on a variable or badly insulated line ; a facility which could not be obtained from systems requiring a duplex balance. This has led to the opinion in some quarters that the duplex Baudot was only suitable for highly insulated circuits such as exist in our paper-insulated cables. This impression is quite wrong, as had been proved on the London–Berlin double duplex Baudot sets before the War ; and also on the London–Glasgow quadruple-duplex Baudot set giving eight channels over a 400-mile aerial line, on an occasion when the underground cable happened to be interrupted temporarily. The reason why duplex Baudot of more than six channels was confined to underground cables was because these cables happened to be available and not at all because of possible duplex troubles on aerial lines.

It is not many years ago since Mr. Hesketh, the chief engineer to the Australian Commonwealth, was in this country seeking advice as to improvements on his main line of communication. As he already had the Wheatstone system in use, he was advised to try the addition of the Creed as a first experiment to see how it suited Australian conditions, and then to try the duplex Baudot. The Creed, although very expensive, was only an addition and not a radical change, and could therefore be tried without much inconvenience. He was told that it would very likely have to give place to the duplex Baudot, but the results and experience gained from the experiment would fully justify the cost incurred. I understand now that the second stage, viz. duplex Baudot, either actually or in the form of Murray multiplex or Western Electric, both of which are practically duplex Baudot systems, is about to be tried, and I hope Mr. Hesketh will be good enough to publish the results, perhaps as a paper to this Institution. Personally, I feel sure of an unqualified success even on these long Australian lines working through several duplex repeaters, and it may be of interest to mention that an experiment was commenced with double duplex between London and Berlin through five duplex repeaters so as to use an entirely underground line between Berlin and the coast. The results were promising, so far as the trial went, but it had not concluded when more important events intervened.

Major Booth.

Mr. Pendry.

Mr. H. W. PENDRY : With regard to the remuneration paid to officers who serve in the colonies and in tropical countries, I found the conditions of living for Europeans were such that any young man going out from England to the tropics should expect between two and three times the salary that he would receive in England. I also desire to support the suggestion of official visits to Europe and America in order to keep up the standard of efficiency. With regard to the Baudot system, I was responsible for the installation referred to on page 110 which did so well ; it just doubled the output provided for in the requisition. The apparatus was cheaply converted into simplex-duplex, and we are able to work duplex daily on that line. The author mentions the ease with which the operators pick up the Baudot alphabet. After a month's tuition of 2 hours per day I have had several operators who could deal with 50 messages an hour. We have nothing in our records of Morse training which will compare with that. With regard to the selection of type-printing systems, one point in favour of the Baudot apparatus is that it is of very solid construction and repairs are seldom necessary. The Baudot receivers purchased and installed 20 years ago are still working well. In comparison of speed, certain experiments showed that where Wheatstone gave 50 words per minute the Baudot would give 100 words per minute, and it suffers less distortion on varying lines. The author's recommendation of secondary cells deserves attention ; it would be well to provide larger conductor leads for distribution to the instrument tables to minimize the drop in voltage experienced when small-gauge wire is used.

Mr. Mansbridge.

Mr. G. F. MANSBRIDGE : In regard to the supply of stores, I have had repeatedly brought to my notice difficulties experienced by manufacturers in correctly meeting colonial indents, owing to the name of the article not being sufficiently definite or descriptive. To provide against this, some colonial administrations have from time to time put forward a request for a copy of the Post Office "Vocabulary of Stores," in which all items of Post Office engineering stores are shown under recognized — and recognizable—titles, and I believe that these vocabularies have proved of great value to engineers in the colonies. The author speaks of dilatoriness on the part of home manufacturers in supplying stores. No doubt he has some reason for this charge, but my sympathy is rather with the manufacturers, knowing, as I do, that they are not infrequently called upon to supply small numbers of instruments or stores of a type not of the latest pattern, and therefore not such as can be supplied without being specially manufactured. Cases have come under my notice where items of current type could have been used, i.e. they were interchangeable with the obsolescent item, and the delay was due solely to insistence on the older type. On page 111 the author (referring to the Wheatstone motor drive) states that the difficulty due to the variation of speed is being got over by the adoption of a larger motor. While it is true that a larger motor is now being fitted, I do not agree that it is the proper way to get over the trouble. The train-work of the Post Office Wheatstone [illegible] a motor developing 10 or 20 times the power, imposes an undue strain upon the train-work and results in heavy wear on the wheels and pinions. The correct method would be to alter the design of the small motor originally fitted so as to reduce the undue heating. In regard to the protection of apparatus from lightning discharges, I would draw attention [illegible] made from metallized paper, as referred to by Mr. Stubbs [illegible] densers, as is now well known, may with impunity be perforated by high-tension discharges, and their successful use for absorbing high-tension discharges in overhead circuits running in the neighbourhood of high-power wireless stations suggests that, in countries where lightning is troublesome, they should be equally successful in protecting apparatus from such lightning or high-tension discharges as get past the ordinary lightning protector.

Mr. J. E. K[illegible] engineering works are being constructed for. The author gives us some valuable facts, and I take two of them as an illustration of my remark. One is of an administration which superintends the construction of the poles and specifies the materials only where the line goes over its own property. The other is of an administration which will not connect any lines to its system until those lines throughout have been properly constructed. In the latter case the administration recognizes what the line is for, namely, to be talked over. In the former case the line might be regarded as nothing more than an ornament to the landscape. Control over connecting lines is one of the first essentials for good service. The tendency on the part of some engineers to regard their own conditions as so special as to require something quite different from anybody else should not receive undue encouragement. In some cases it may be quite true, but there is one respect in which a Crown Colony differs in no regard from that of a metropolitan city. The telephone serves the same purpose in both, to give communication among the inhabitants, and the more people it serves the more good it [illegible] it might be used in certain cases "because the commercial [illegible] telephone is an educative institution and commercial conditions respond to its influence. The conditions in certain localities may require the material to be treated in some special way, but I very much doubt whether there is any locality which requires a new system or a system that in [illegible] system I do not mean any particular construction, but the [illegible] conclusion that the local conditions will not permit the [illegible]"

Mr. [illegible] mence again similar to a "hammer action" and perhaps veer round in exactly the opposite direction. Even on lines which have been constructed on the best engineering principles and where typhoon troubles have been taken into account, I have seen a lot of the line brought down. The next thing to which I wish to refer is humidity. I tried to get a telephone company to install a central battery [illegible] humidity very often of 100 per cent. They would not do it; but I am glad to hear one speaker say that he thinks we are coming to the time when we need not fear installing central battery systems even under the most adverse conditions of humidity. Another point is in connection with the interior wiring of buildings, for telephones, where the water runs down the walls in streams. It has been found in the Far East that if the wires are lead-covered many of the troubles which previously existed will cease. Small insulated lead-covered wires are used, the wires being joined by a lead strip, and the wires are clipped up by the lead joining the two separate wires. Next, in regard to corrosion, when we get so much humidity it is essential that any iron or steel parts should be very carefully treated. Not only should they be galvanized, but special precautions must be taken with regard to their maintenance. So far as the use of copper wire for telephone or telegraph lines is concerned, it is not only an engineering problem but also presents other difficulties. For instance, in China it was found that the Chinese stole the copper wire, and for that reason copper or bronze wire has very often not been used. In a system with which I had to deal in the north of China, we had very peculiar conditions to face. We had not only intense cold but high winds, great humidity, and much fog. It was found that the lines used to get very much bigger in diameter due to the frost, necessitating most careful staying of the poles and shorter spans. The conditions were very much more severe than those when snow only is present. I should like to refer to the question of harbour cables. Very often in the colonies there are a number of islands between which submarine cables are laid. It was found a very common thing in China during typhoons for the junks to drag their anchors and incidentally to drag the cables. They have had so much trouble in one colony that now, after a great deal of pressure, an anchorage limit has been fixed, within the area of which no vessel is allowed to anchor. This has proved to be a very valuable provision and it would have saved a great deal of trouble if it had been done initially. Even when this anchorage limit had been arranged, trouble would sometimes arise, and in one instance when a new telephone cable was laid it was designed so that it would hold the largest vessel without breaking. I fully agree that it is of the utmost importance adequately to pay engineers working abroad. The conditions are entirely different from those in England, and an engineer must be prepared to fall in with the social rules of the place or be ostracized. I desire to add my testimony of the value of this paper because I know that electrical engineers abroad look to the Institution as the headquarters of electrical engineering in the British Empire.

Lieutenant R. T. McArthur: The functional organization adopted in South Africa in 1912 has been found to be [illegible] protection means a great deal to us in South Africa, and I am afraid we are still not clear as to the actual type of protection that should be adopted. Not only are the Post Office engineers devoting their energies to the subject, but it is also receiving particular attention from the technical staff of the Eastern Telegraph Company. So far we have found the carbon vacuum protector, as an inside protection, the best, but I fully agree with the author's statement that on many of the outside stations protection on the outside is really essential. At the same time I think it must be borne in mind that in South Africa, in view of the great length of the lines and the large extent of territory, we can have too much protection, and that has caused a great deal of trouble in carrying out experiments. In German West Africa the Germans have adopted a carbon vacuum protector, but in conjunction with it they use the old double-plate discharger of the brass pattern, and have a suitable earthing device for earthing the lines during heavy storms. In connection with Sir William Slingo's remark about one of the lantern slides, I should like to point out that all the stays are on the same side of the railway as the poles. Dealing with the question of telephone systems, I may say that the automatic clearing system which has been so largely adopted in South Africa has practically been discarded, and they are now very busy converting that system. It has been found that with the enormous extension of the trunk systems the loss of speech efficiency is so great that it has been necessary to look into the matter further. Up to 100 lines in small towns they are using the magneto system, and beyond that they are going in for the central battery system. At the present moment they have 100 line lamp-boards in use and these have proved very satisfactory.

Mr. Newlands.

Mr. J. NEWLANDS (*communicated*): It is satisfactory to have it stated that in the colonial telegraph services generally the British Post Office practice is accepted as beyond question because of the conviction that the home department has tested out its practice by many years of experience and its procedure has been well thought out before being finally adopted or recommended to other administrations. It is well known that the British Post Office gives every reasonable facility to inventors in order that new and promising systems may have a fair and full trial. In recent years the general trend has set in strongly in favour of type-printing telegraph apparatus for circuits carrying heavy loads. The battle for supremacy has chiefly centred around two points. (1) High-speed telegraphy by means of slips, prepared by keyboard perforators, which are run through a single transmitter at high speed as on the Wheatstone plan. (2) Multiplex telegraphy where from two to twelve separate channels may be worked—either by hand manipulation or by keyboard—on one circuit at a relatively lower speed per arm. The former system includes the Wheatstone with the adjuncts of Creed re-perforators and printer, also the Siemens with its somewhat costly broad perforated slip and its noisy printer. These systems require more supervision. In both cases the received typed slip is gummed on the forms and all errors or erasures can be cut out so that a clearly printed message is the result. The latter or multiplex system includes the Baudot and the Western Electric. After 47 years of experience it is an established fact known to all practical telegraph officers that in each and every system of high-speed telegraphy delay in transmission is both inevitable and inseparable from the use of such apparatus, and that whenever corrections are required this delay tends to increase. On the other hand, multiplex telegraph systems admit of instantaneous direct signalling and printing, while corrections can be asked and given with celerity and a minimum of delay, and therefore these systems are admittedly far more efficient than all others for the rapid transmission and disposal of ordinary public telegrams. Expert Baudot manipulation can be taught to a telegraphist in approximately the same time as keyboard perforating can be acquired by a new beginner. In my judgment the proper sphere of a high-speed system such as the Wheatstone with or without printing adjuncts lies in its utility in the treatment of Press work, also in its usefulness in sudden emergencies such as breakdowns. For an ideal means of coping with a large traffic in public telegrams between two large centres the duplex Baudot with its multiple channels available at will stands easily in the foremost rank. It is sure and certain; it is far less costly to maintain; the staff like the style of working, and the apparatus can be safely left in their hands provided one or more of them be trained to act as a competent *dirigeur*. Certain other systems require far too frequently the attention either of skilled mechanics or even the time and attention of more costly engineers. These are very vital and important factors. It may be worthy of mention that during this month (December 1916) a telegraphist in the Central Telegraph Office signalled by hand no fewer than 96 telegrams in an hour over one Baudot sending arm to Bristol, while on the five duplex Baudot arms of the same circuit on a more recent date as many as 546 messages were disposed of in one hour, and 501 in the next hour. The duplex Baudot is largely used in London up to quadruple, quintuple, and sextuple, thus giving 8, 10, and 12 working channels respectively. It has practically displaced all other systems of working to and from the continent of Europe. It may therefore be said with truth that it has demonstrated its extreme suitability to meet all the requirements of the British postal telegraph service. By and by it will be provided with a keyboard perforator and its working speed will then be considerably increased. Later on, the French practice of utilizing the Baudot to serve three or more offices on one extended circuit will be found most useful for linking up with a far more satisfactory service many of the large provincial centres in Great Britain. Another battle has raged over the question of "page printing" versus "typing on a single slip" and gumming. After watching both operations during the course of a lengthy service I am decidedly in favour of the typed slip. Page-printing introduces too much mechanism and the product is not very creditable when viewed critically. The page-printed message somehow or other does not look like a public telegram.

Mr. Harrison.

Mr. H. H. HARRISON (*communicated*): This paper is difficult to discuss as it raises no controversial points. It is, however, none the less valuable on this account. To administration engineers it is interesting as illustrating diversions from European practice. To the manufacturing engineer it is valuable as a guide to modification in materials and methods. The author has shown how widespread is the adoption of British Post Office practice. This is a most satisfactory policy. It not only leads to

Mr. [illegible] [illegible] methods, but, and this is of great importance, [illegible] standardization in manufacture with all its resultant economy. Australia is still somewhat of a sinner in this respect, inviting tenders from British manufacturers for small quantities of telegraph apparatus, the patterns for which are obviously of American origin. The slides shown by the author reveal the excellence of pole-line construction in South Africa. Both from the engineering and æsthetic standpoints this is excellent. On page 109 the author mentions the electrically-driven distributors used with the Baudot system in Ceylon. This is reverting to Baudot's original method and it would be interesting if he would state how the speed is governed. That the Morse duplex will remain a standard type of circuit seems to be the author's opinion. I cannot quite agree with him here. As printing-telegraph networks develop, the single-channel low-speed printer adapted to be operated by a five-unit tape and also able to furnish such tape if required will, I believe, come into extended use. There will then be no need for re-transmission in the case of *x* messages. On page 112 the author makes some remarks as to the reorganization of traffic circulation in Australia. With the general adoption of a uniform printing-telegraph system, the arrangements described would be better met and with advantages to both the administration and the public.

Mr. Byng. Mr. E. S. Byng (*communicated*): On page 114 the author prefers using armoured underground cables for small exchange systems, and I should like to ask if this is intended to apply to all cases or merely to specific instances where subsidence of the ground might endanger the safety of an earthenware or fibre duct. A question of this description should surely be decided after making an economical study of the local conditions, for although it is true that the initial cost of armouring may be less than the provision of a duct, yet it is more than likely that a consideration of the present value (P.V.) costs, say at 15 years hence, would indicate that the duct was the more economical under normal conditions. The costs would take account of the alterations which may be necessary to the cable after installation, repairs or replacement of the cable in the event of breakdown, and also the scrap value which could be realized upon its recovery. There is a further point in favour of a duct line which should not be overlooked even for a small exchange, viz. that it is only necessary to provide a cable initially for the 5-year planning period (see page 118), and an additional cable to meet the ultimate development can then be drawn over when required, rather than having to lay an armoured cable at the outset for the total development anticipated, thus entailing an idle investment for some years, unless, of course, a second armoured cable be provided at a later date, which would involve breaking up the ground again. Perhaps, however, the author will be able to clear up this point in the reply. Reference is made on page [illegible] to phantom circuits being used on long-distance routes in Canada and also to some extent in South Africa (page [illegible]), but apparently in the other colonies this method of obtaining a third circuit from two existing telephone circuits has not been adopted. This may be due to one of two causes: (1) The amount of the loss in transmission introduced by [illegible] the efficiency of the existing circuits [illegible]; or (2) as a result of experiments made by [illegible] circuits which, although they previously gave fairly good results, yet the line conditions were so poor that upon the introduction of a phantom circuit all three circuits were noisy and rendered uncommercial. In regard to No. (1), it is admitted that some of the earlier repeating coils introduced a transmission loss into the circuit which, evaluated and expressed in terms of standard cable, was equivalent to approximately 8 "standard miles." For long-distance circuits this was a very serious item as, in the case of 300 lb. copper wires, this was practically equivalent to increasing the distance of the route by 160 miles. Manufacturers very soon recognized the importance of an economical utilization of all possible circuits on long-distance routes, and therefore specialized on the development of a more efficient repeating coil, with the result that a coil has now been put on the market by the Western Electric Company, designed on highly scientific grounds so that when coils are placed at the two ends of a line the loss in transmission is under one "standard mile," a further advantage being that they permit of ringing over any circuit which can be used for satisfactory speech transmission. Regarding No. (2), it is now generally understood that, in order to get well-balanced lines, the two physical circuits must have similar electrical constants, and in addition there must be a systematic arrangement of these physical circuits which will eliminate the mutual disturbances that give rise to "cross talk." Given, however, that the insulation resistance is sufficiently high, it is possible so to balance the lines that no overhearing can be detected, and in fact the efficiency of the third circuit is even greater than that of the component side-circuits. If it were always borne in mind when new routes are being designed and erected, that for each pair of telephone circuits installed it is possible to obtain a third circuit with no greater cost than that of the repeating coils and a few simple transpositions, it would obviously be economical to expend a little more capital on the line construction, and thus obtain these efficient phantom circuits, than to install additional physical circuits which not only increase the initial cost but also the annual cost for maintenance and depreciation. There is a further point in connection with these long-distance aerial routes which should be mentioned: apparently in none of the colonies has aerial loading been attempted with the exception of Canada (page 117), although the author states that in several countries its introduction is now under consideration. The general effect of aerial loading is not only to increase the distance over which commercial speech is possible but also that a smaller gauge of copper can be used. The same grade of transmission can be obtained for a loaded line as would be obtained over the present one unloaded if it were twice the length. In other words, the transmission length of a line is reduced by about one-half. This figure is conservative, and in all probability where good insulation resistance is possible the improvement would be [illegible]. The insulation resistance plays such an important part in the case of aerial loading that in order to get the greatest benefit from the use of loading coils special care must be taken that the insulation of the line is maintained at a high figure, particularly where heavy-gauge conductors are involved. This is a further argument for the good line construction which the author has urged so frequently in his paper. In regard to the economy which can be effected in the weight of yng.

wire used, it is possible by adopting a suitable system of loading to obtain the same results by using 250 lb. copper wires as if 400 lb. copper wires were used unloaded, thus saving 150 lb. of wire per mile. It will be seen that for a long route and with the price of metal based even on a normal market, this would represent a considerable economy. As the result of the extensive development during the past three or four years it is now possible to load successfully the phantom circuits, thus getting three highly efficient loaded circuits from two pairs of wires. This new feature should prove a great incentive to all those interested in telephone engineering, especially in the colonies where it is necessary to connect up towns which are at such distances apart as shown in Fig. 8 and where the climatic conditions are so favourable.

tman.

Mr. R. W. WEIGHTMAN (*communicated reply*): I wish to tender my best thanks to all those gentlemen who have taken part in the discussion for their very complimentary remarks on my paper, and also to all members present for the cordial reception they have given it. I specially thank the colonial engineers who have spoken, for the hearty support they have given me.

All colonial engineers will appreciate the excellent spirit of camaraderie underlying Colonel Ogilvie's remarks. It is that spirit, actuating, as it undoubtedly does, the whole of the administrative and technical staffs of the Imperial Post Office, which has done so much to maintain the happy and desirable relations between the staffs of the home department and the colonial administrations. The best traditions of the Post Office are behind it, and long may it continue.

Mr. Preece's remarks on administration are much to the point. In the larger services the form of administration is all important. Upon it depends the policy of the department; and its attitude towards the telephone makes for or mars development. The functional system, as introduced in South Africa, is the ideal one where the organization is sufficiently large. In the smaller services the position of the engineer should be fully recognized. He should be given that full place in the sun to which the importance of his work entitles him. The point brought up in connection with the New Zealand totara poles is most interesting. The charring of poles not properly seasoned will cause decay to set up owing to the sap not being able to find an outlet through the charred surface of the pole, and this may account for the poles which were not charred standing longer than those that were treated.

Mr. McBerty's contribution on the development of the telephone and the application of the automatic system in Australia and New Zealand emphasizes my remarks on the policy towards the automatic system in these countries, and should be of interest to all telephone administrations. The paper by Mr. Hesketh, to which he refers, should help to settle the question of the operating costs of the automatic as compared with the manual, on which the information so far available has not been very reliable.

Sir William Slingo has raised several interesting points. I do not recommend the 4 in. spacing where snow-storms occur, but in Natal, where I adopted it on telephone distribution lines, very heavy wind-storms are frequent. It is the standard spacing to-day in South Africa on lines of this class. Lieutenant McArthur has already replied to the question as to the stay crossing the railway. Any stay wire across a railway was erected at a proper height to clear the traffic on the line and terminated on a pole. Poles alongside a railway were as far as possible planted so that they would not foul the track in the event of their coming down accidentally. What Sir William says about administration is quite true. Unfortunately, it is not always easy for an engineer to convince the higher powers that the stage has been reached where greater specialization should be introduced. The amount stated by Sir William as the value of his reserve stock, which is based on one year's consumption, viz. £2,000,000, is staggering. This statement should be helpful to those colonial administrations which are now considering the establishment of reserve stores, and also to those who have so far not been able to induce their Governments to provide the necessary funds for the purpose. Sir William's reference to the factor of safety of 4 which I have suggested for iron poles, is no doubt prompted by recollections of the terrific amount of damage which his lines suffered in the blizzard last March. A factor of safety of 4 would obviously not be sufficient in these circumstances, but I know of no country where poles of the character I have referred to are used, where conditions even approaching those of the blizzard are ever likely to occur. It would have been helpful if Sir William had given us a résumé of the conclusions of his department on this subject. It is noteworthy that the superintending engineer of the North Midland district (Mr. A. Watts) in a paper on the breakdown in his district, on page 235 of the October issue of the *Post Office Electrical Engineers' Journal*, states: "In future designs the calculation of the factor of safety should be made on the assumption that every wire is surrounded with a ½ in. coating of ice, i.e. a total diameter of 1 in. plus the diameter of the wire. The wind pressure would be calculated as at present, but the factor of safety would then be reduced to two by suitable span adjustments." This practically agrees with the factor of safety of two suggested by me for countries where snow and ice on the wires are unknown. In India the working load of the Hamilton pole formerly allowed a factor of safety of 1·46, with an allowance of 25 lb. per square foot for wind pressure. More recently different wind pressures have been fixed for different localities, the average for 32 places being 14·25 lb. with the factor of safety the same as before. The difficulty of making a satisfactory hollow reinforced-concrete pole without the aid of mechanical processes would, no doubt, be in the way of its adoption in New Zealand. The solid poles are made in moulds and in the vicinity of the line. One firm in England makes hollow poles of about one-third the weight of solid poles of equal strength. The reinforced concrete is consolidated under heavy pressure by an automatic process, and it would only be by some such process that hollow poles could be relied upon.

Mr. Weightman.

In reply to Mr. Walker, aluminium wire is not used at all for either telegraph or telephone lines in any of the dominions or colonies. It is used to a considerable extent in different parts of the world for power-transmission lines. Its cost, as a rule, would be higher than copper for the same conductivity, and, moreover, its larger area for wind pressure, and the difficulty it presents for soldered joints are against it for telegraph and telephone lines. On long-distance telephone circuits, one or the other of the standard methods of spacing the wires must be adopted

Mr. Weightman.

[illegible]. In my own experience I have found that where telephone circuits are carried on [illegible] where the latter are worked with high-speed apparatus, or where vibrators or phonopore buzzers have been superimposed on the telegraph circuits, the twist method has been the most efficacious in eliminating inductive effects in the telephone circuits. Of all instruments that give rise to trouble in telephones, the buzzer is the most pernicious, and it is to be avoided on lines carrying long-distance telephone circuits. Where there are no telegraph or other disturbing circuits on the same poles the transposition system is quite satisfactory, and from the constructional point of view is preferable to the twist. On exchange distribution open wires may be run straight, and without crosses, for considerable distances, especially in a dry atmosphere, and in this case it is an advantage to keep the two wires of the pair as close together as is practicable, with as wide a space as possible between the pairs. The spacing on the 12-wire arm shown in Fig. 4 of the paper illustrates this method. Mr. Walker's explanation of the use of heavy-gauge iron wire in some of the colonies is interesting. I have always thought it a survival of the old days when a No. 4 iron wire was regarded as the ideal for a long-distance telegraph circuit.

Mr. Moir has brought up one of the most important questions of the evening, that of the air-space versus the boiled-out joint. Mr. Kennedy refers to the same question and this reply will cover the points raised by both. My reference to it has been correctly interpreted by both. Personally I do not see any practical difference between the boiled-out and the solid joints, in so far that neither allows the free circulation of air. Of the two, the boiled-out joint is perhaps the more solid, and certainly the more reliable, as in making the solid joint, unless very great care is taken, there is a risk of the compound not penetrating right into the heart of the joint even when it is forced in under pressure. Much of the low insulation trouble on cables with air-space joints undoubtedly occurs at the joints, and with the boiled-out joint the possibility of [illegible] is a very rare occurrence indeed, and the joint is found to be so reliable that no desiccating plant whatever is provided or required. Mr. Moir appears to dislike the risks in connection with the handling of the boiling wax in the streets and manholes, but if this can be done with safety in America [illegible] to study and report on the matter? [illegible] closely looked into throughout the colonies. Apart from the great advantage of freedom from maintenance trouble, the boiled-out joint is undoubtedly the more economical [illegible]

Mr. Crawter has apparently read the paper very cur- [illegible] part. My point, which I take it is [illegible] tions to expect their telegraph and telephone engineers to [illegible] probability is that the engineer will not be really expert on either. I do not say that "complaints from weak signals (from a secondary battery) are not often received," but "there are no complaints of weak signals." In no other statement that I have seen has the case for secondary batteries for telegraph working been put in stronger terms than by myself in the paragraph he alludes to.

Mr. Weightma

Mr. Monckton's account of the conditions in far away Fiji is most interesting, and I feel that it was distinctly to the advantage of the meeting that he was able to be present. His anxieties are many and varied, and not the least of them, I dare say, is the flying about of the sheets of galvanized iron during hurricanes. He refers to the question of standardization, a most important one, and one which I will deal with more fully later.

In reply to Mr. Aitken, the barrel insulator is correctly shown as in use in Australia. The insulator with two side knobs for the two wires of a circuit should only be used in sheltered situations. Where it is exposed to dampness it is altogether opposed to the principle of high insulation which is aimed at in a high-grade double-shed insulator, and in the pot-head of a leading-in insulator. I am not familiar with Mr. Aitken's ring-through system, and I am not aware that it has been introduced anywhere. I can, however, speak with long experience of the satisfactory working on small exchanges of the system described in the paper. I mentioned the train-despatching services in Canada in connection with the railway telegraph organizations there, but the scope of the paper did not permit of the subject being dealt with.

In answer to Mr. Gill, the trouble at Port of Spain is the low insulation of the open lines, due to contact with vegetation. The remedy, it may be said, is better maintenance (not always easy of accomplishment in these countries), or covered distribution. The exchange is, however, a small one, and its trunk network is also small. The manager's opinion is that the magneto system would have met the local requirements better than central battery, and he is no doubt right. To keep up the insulation and to prevent the deterioration of the exchange cables and equipment which will otherwise take place where circuits are continuously under electrical pressure, electric radiators have to be regularly used, and this is necessary at most exchanges in the hot and humid places of the tropics. With the magneto system the effects of dampness are nothing like so troublesome, and satisfactory working is possible without those extreme measures of precaution which are so essential with the central battery. It is therefore, in my opinion, advisable in the case of a damp tropical place to consider well the conditions and the probable development before deciding upon a central battery. If the development is not likely to go beyond, say, 1,500 to 2,000 lines within a reasonable number of years, then I would advocate the magneto. If the probable development warrants a central battery the best materials should be selected, coils should preferably be made moisture proof, and a means of drying out regularly of the exchange should be provided and used from the outset. It is a mistake to wait till trouble begins to show itself, as it otherwise certainly will do. I have a recollection that certain exchanges in the Philippines, and notably one at Manilla, were not long ago converted from central battery to magneto owing to trouble of this nature.

ghtman.

In one case a special plant was installed for forcing dry warm air through the floor of the exchange, but it was not successful in removing the trouble. One other point is that if a place is really suitable for a central battery at all, it is probably suitable for the automatic system. Mr. Gill says with regard to the case he had in mind that he thinks he knows where the trouble is and how to get over it. It would have been instructive if he had given us some information on these points.

Mr. Gill's complaint that the paper does not deal sufficiently with economic questions is rather ungenerous in view of the length of the paper and of my explanation in the first paragraph thereof. The paper had to be curtailed by a third of its original length, and complete sections, some dealing with economic questions, were cut out. My reference to 70 lb. copper is more particularly a comparison between this and 40 lb. bronze, which is very largely used for distribution purposes throughout the dominions and colonies. His own figures, which I thank him for, bear out my contention. While the cost of the 70 lb. copper is only 22·6 per cent higher than the 45 lb. bronze, the speaking efficiency is 171·4 per cent better. As to the use of iron wire on exchange distribution, I quite agree that in the designing of an entirely new system of local exchanges, with junction and trunk circuits, the speaking value of every part can be predetermined, and iron wire can perhaps be given its allotted place provided the atmospheric conditions are suitable. But in actual practice, and in the countries I had in mind, this is not the case at all. In Natal in my own time, practically every town and hamlet was connected through the trunk system on circuits which were nearly all arranged on wires converted from telegraph purposes to the use of the telephone system. The main trunk circuits between Durban and Johannesburg were arranged in this way. This is typical to a great extent of the method of building up telephone systems in the colonies. The local exchange areas are unavoidably large and scattered. Many subscribers' lines will be a good many miles in length, and even with copper lines they will be over 1,000 ohms. The speaking limits over the trunk network are a fixed quantity in miles of standard cable, and the deciding factor in the bringing of a local exchange on to the trunk system, or the distance over the trunk system it will be able to communicate, will be the speech efficiency of that exchange, and the character of the distribution lines may be the determining factor in the matter. In such conditions I contend that the 70 lb. copper is the most advantageous to use. It may be argued that iron wire should be used on the shorter lines. Iron and copper could not be erected together on the same poles, and in any case the mixture of conductors would be bad for maintenance, especially with native workmen, who would not differentiate between copper and iron in carrying out repairs. Moreover, the better efficiency of the copper wires on the short circuits would be all to the advantage of the subscribers in their long-distance conversations, and especially so where they are verging on the extreme speaking limits of the system. On a purely local exchange there is, of course, nothing against the use of iron wire provided the local conditious are suitable. In a humid climate, or in a smoky locality or near the sea, the galvanizing does not stand long and it is therefore not economical to use it in such conditions. The open distribution at Shanghai is all iron. Again, on telephone lines that are never likely to go through to a trunk network, there is also room for it. I, however, have a number of iron-wire circuits in mind which were erected before the trunk system was thought of, but the speech efficiency was so low that they could not be connected through to any distance on the trunks.

Mr. Weightman

I note Major Booth's remarks as to the motor distributor. At the time that part of my paper was written I was told the Post Office had not introduced the motor drive for the distributor. Another difference is that the Ceylon receivers, as well as the distributors, are driven by direct worm gearing, as against the Post Office belt drive. Major Booth's comments on the multiplex systems will carry all the weight which his great experience with these systems entitles them to. I am not quite certain that it is intended to substitute the multiplex for the Creed on the Perth-Adelaide line, but if the line conditions are suitable for the Creed, as appears to be the case, although the working speed is not stated, there is no reason why the multiplex should not do equally well, or even better. Major Booth's opinion that it will be an unqualified success on this line will be encouraging to Mr. Hesketh.

I am glad to find that Mr. Pendry's views, after his experience in Ceylon, are in accord with my own on so many points. Much credit is due to him for the excellent results he obtained from the Baudot plant he installed at Colombo on the 800-mile line to Madras, and especially for his success in duplexing the circuit.

Manufacturers will feel indebted to Mr. Mansbridge for his defence of them. My remark, in view of the coming "War after the War," was intended to be just the light touch of the spur to the spirited steed. I am not sure if all British manufacturers realize how the dominions and colonies have tried to help them in the past. To give only one instance, South Africa allows a rebate through the Customs on all goods of British manufacture, the object being to help the industries of the Homeland against German competition, and mainly because the people have realized that every penny spent in Germany was a contribution to the making of a rifle or the building of a warship with which to fight us sooner or later. What is going to happen after the War when the menace of Prussian militarism has been destroyed and when the bitterness of it all has subsided? It is a big question, and it behoves our great captains of industry to be fully alive to it. There will be no room for slackness, or dilatoriness in the future. I quite agree that the larger motor on the Wheatstone transmitter is a makeshift arrangement, but it is perhaps the best that can be done until after the War. The most satisfactory motor-transmitter set for the Creed is no doubt the Great Northern Company's set, but it is larger than the Post Office set, and it does not fit in with standard instrument-table arrangements. I do not agree that the paper-foil condenser is suitable for the purpose of a lightning discharger; besides, my contention is that with a proper discharger outside there is no need for protection inside. I refer further to this point in my reply to Lieutenant McArthur.

[illegible] method, and there is nothing I would better like to see as a result of my paper than that an effort at general standardization should be made, so far as the Crown Colonies are concerned, at any rate. Several speakers have referred to it and there is no practical difficulty in [illegible] of things of a pattern differing very slightly from the Post Office standard. This is quite true. It is, however, wrong; it hampers the manufacturers and increases the cost to the colony, and no real advantage results anywhere. The one and only obstacle is that due to the personal preferences and prejudices of the individual engineer.

Mr. Williams refers to submarine cables across harbours. I could not deal with this subject owing to the length of my paper. It is, however, usual to indicate the positions of cables across harbours by means of conspicuously placed signboards or plates, and also by buoys. In fast-running tidal channels, where vessels may have to drop anchor suddenly anywhere, it is advisable to dredge a trench in which to lay the cables. In the case of an open anchorage it is necessary to keep the cable quite clear of the anchorage, even if this should mean making the cable longer, or erecting a length of land line to connect with it.

I am specially pleased that Lieutenant McArthur, one of my old colleagues in South Africa, has been able to take part in the discussion, and I cordially thank him for the support he has given me. It is noteworthy that the present practice in South Africa is to use central battery for exchanges with over 100 subscribers. Regarding lightning dischargers, I am convinced that in a bad lightning country, the principle of placing a lightning discharger inside a building is wrong. Lightning should be given an adequate means of discharge outside, with the earth as direct and as good as it can be made. The earthing device found in use in German South-West Africa is also wrong in principle, as it involves closing down the circuit during lightning storms. This practice is followed in some of the Crown Colonies, especially on railway signalling circuits, but it is a costly procedure, inasmuch as it disorganizes the traffic and causes delays to trains, with all the resultant expense in train-men's time, engine fuel, etc. With proper lightning dischargers placed outside the building there is no necessity to earth the lines during storms.

I am much obliged to Mr. Newlands for giving us the [illegible] lines of the Post Office. For ordinary public telegrams he speaks with great clearness [illegible]

Mr. Weig

is maintained on each channel. The keyboard operators quite easily keep up with this speed for long periods, and they have no difficulty in increasing it to 50 words a minute when occasion demands it. The regular speed of the Baudot is 30 words a minute, so that for the same staff the Western Electric shows a normal 50 per cent superiority. The working speed of the Murray is similar to that of the Western Electric. Mr. Newlands sounds the death knell of the Wheatstone for commercial work, although he still gives it a place of usefulness in cases of breakdown, and also for Press work. But even for these purposes I am inclined to think the value of the Wheatstone may be overrated, in view of the great efficiency of the Western Electric and the Murray systems. With either of these in use there would be no thought of introducing the Wheatstone as a standby for breakdowns, and I assume Mr. Newlands only refers to the Wheatstone in this connection because of the fact that Wheatstone apparatus is already installed and available in practically every important office in this country. There may still be a sphere for it for public telegrams where long distances separate the principal centres, as in South Africa, and where, owing to a paucity of wires, there may be serious delay in making good a busy line in the event of its breaking down. Here the Wheatstone has the advantage that during the breakdown the work can be punched up, and, on the line being restored, run through to an ordinary Wheatstone receiver at the highest speed the line conditions will permit. Where Creed apparatus is used with the Wheatstone, this advantage, as compared with the multiplex, disappears at once, as, with the latter, more words per minute can be got through on any given line. On the other hand, serious delay in restoring a line is the exceptional thing, and the system to be adopted should not be considered from this point of view. It should be the one which will give the most satisfactory results from the point of view of both speed and economy under everyday working conditions. Where there is a considerable telegraph network, and alternative routes are readily available, it will only be in the case of a breakdown of exceptional magnitude, as during the blizzard of March last in England, that there is likely to be any delay in making good an important circuit. This being so, it appears to me that with the multiplex in use, the Wheatstone could be dispensed with altogether. For Press work also I believe the days of the Wheatstone are numbered. This view may not find acceptance at the Post Office, where the system of Press distribution, unequalled anywhere in the world, has been built up on the Wheatstone method of transmission. The system is, however, admittedly a costly one, although no doubt the best that has been available in the past. But those features of the multiplex which have made it so great a success for commercial telegrams are applicable with even greater force to Press work, where the same services could be sent over the same wire simultaneously to a great many different newspaper offices, and it requires no great amount of prophetic instinct to forecast the adoption of this system for this work. With the great flexibility which the multiple channels of the multiplex afford, with its re- [illegible] htman.

Press distribution, and the one which can be worked with the minimum of delay and cost of operation.

In reply to Mr. Harrison, I have not details at the moment of the method of governing the speed of the distributor, but I will obtain these and let him have them personally. I hope Mr. Hesketh and the officers of the Commonwealth Administration will note Mr. Harrison's remarks as to American pattern apparatus, and with the other dominions and colonies keep before them the great ideal of common British standards throughout the Empire. I trust Mr. Harrison's views as to the development of type-printing networks will be realized. It is the ideal of the press-the-button system advocated by Mr. Donald Murray. But from what I have seen personally of type-printing instruments I feel that they are so delicately constructed that they cannot be used at too great a distance from a skilled attendant or mechanician, or where a supply of current is not available. It therefore appears to me that they will only come into general use for heavy-traffic lines, and here the traffic will of course justify the cost of the special attendant.

Mr. Weightman.

In reply to Mr. Byng, I expressed the preference for underground armoured cable as against aerial cable for distribution on small exchanges. To what extent I would use armoured would depend entirely upon the probable development, but the probability is that it would not be economical to use it beyond a single cable in any direction. With any promise of development, ducts would be used. I am of course aware that aerial dry core is used extensively in America and Canada. My objection to it is, firstly, on the ground of the heavy stresses it throws upon the pole lines; secondly, on the ground of its liability to give trouble; and thirdly, on the ground of its unsightly appearance. I am not sure that I should not have put the third objection first, as I am in full sympathy with those municipal and local authorities who insist upon a proper regard for amenity in overhead construction work in the streets and suburbs of towns. Everything is, in my opinion, in favour of the armoured cable from the maintenance point of view, which, in the case of the overhead cable, concerns not only the cable itself and its means of suspension, but also the pole line. While the initial cost of the armoured cable may be slightly greater, its upkeep is practically nil. Most of the administrations in the colonies that have used aerial cable have had trouble with it. I have referred to this in my remarks on New Zealand. South Africa has recently had serious trouble. In all cases the lead is hardened by an admixture of 3 per cent of tin, but, notwithstanding this, crystallization troubles and fractures have occurred. I believe the trouble is due mainly, if not entirely, to faulty suspension. Anything that is liable to become tight on the cable will check the free vibrations in the lead, and where this occurs, crystallization will be set up. I have mentioned the tarred Marline hanger as being the best in my opinion for tropical use. It should, however, be used as a loop, and not as a slip knot. In South Africa, the latest American-pattern galvanized ring hanger has been tried, but this has caused trouble. The edge of the ring on which the sheathing rests dents the sheathing, and in time wears it through. This it seems to me is just the effect that might be expected. This defect has only recently been brought to my notice, and I regret I have not had time to find out whether it has also been experienced in Canada or America. In this connection it is worth while to call attention to Mr. Welbourn's paper[*] on "Transmission Lines," in which he describes the Elder system of suspension for lead-sheathed cables. Mr. Welbourn informs me that this system has given complete satisfaction. My remark as to the use of phantom telephone circuits in South Africa is: "Phantom telephone circuits are obtained wherever possible." This is also the case in the Crown Colonies. The efficiency of the repeating coil as used to-day is given on page 117. Mr. Byng's remarks on the value of the loading coil, cover a feature of telephone practice not so far touched upon in the discussion, and they are of special interest for this reason. Every telephone engineer is alive to the value of loading coils, and but for the War they would, no doubt, have been in more extensive use in the Dominions. In the tropical colonies the difficulty of maintaining the high line insulation necessary may be an obstacle to their adoption in some cases. In a bad lightning country special protection, preferably on the lines of the Wurts discharger referred to in the paper, which will take off discharges without earthing the wires, should be provided as part of each coil.

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[*] *Journal I.E.E.*, 1914, vol. 52, pp. 189 and 190.

NEWCASTLE LOCAL SECTION.

ABSTRACT OF LECTURE

By H. W. CLOTHIER, Chairman of the Local Section.

(*Lecture delivered 11 November, 1915.*)

Mr. Clothier said that owing to the pressure of the times he had found it difficult to settle down to the preparation of an address up to the Institution's standard.

He paid tribute to those men who had answered the calls from the Navy and Army, but he said that the way in which the majority of those engaged in the manufacturing industry had to fight at the present was to multiply their output and to develop with the future in mind.

As the perfection of output is now so freely acknowledged to be of national interest, he thought he need make no excuse for selecting as a subject one for which credit was due to engineers in this country, viz. "The Development of Armour-clad Switchgear of the 'Draw-out' Type."

The fundamental features of the design were:

(1) The oil-break switch.
(2) The ironclad enclosure of conductors.
(3) The "draw-out" principle.

Each of these features was of early British origin. For instance, he illustrated an oil switch designed by Partridge and used on cable mains in 1892, another by Ferranti used on power-station switchboards in 1894–5, the use of ironclad pillars for generators by Raworth a year or so earlier. The "draw-out" principle, or the easy detachment of complete working parts, was also initiated on the Ferranti slate-cell gear. Ten years afterwards, acting upon the advice of the engineers of the North-East Coast power companies, these main features were assembled on the gear called the "ironclad" type, which includes the enclosure of busbars run in solid with compound (developed about the same time by Highfield), and the covering of each conductor or limb with armour. Owing to the subsequent introduction of other metals than iron for the casing, for instance steel for switches and aluminium alloys for use in proximity to conductors carrying very heavy currents, he preferred now to call this gear "armour-clad."

He demonstrated the progress that had been made in the last decade by showing designs prepared in this country by several manufacturers. All of these had one common purpose, viz. to meet the characteristically British demand for apparatus solid and substantial in its construction, perhaps more expensive than some other forms but having the humane feature of affording the maximum protection to life.

As there was a similarity of purpose so there was a similarity in designs, and though standardization might be too much to consider at the moment, he thought it was not an impossibility, particularly for three-phase 400- to 3,000-volt use.

It has been said in a recently published book that ironclad "draw-out" gear was "suitable for mining and sub-stations, but with control board requirements of a central station the arrangement no longer possesses the advantage of simplicity." He did not agree with this statement. In cases where a control board is requisite, the design of the control board presents no more difficulties with armour-clad gear than with any other form of gear; in fact, in some instances the control board has been considerably simplified on account of the use of armour-clad gear.

Dealing with larger switchgear, he thought the near future would decide in favour of the use of armoured principles for all sizes of plant and power stations. He illustrated examples of large power station switchgear and said that the chief problem was the necessary strength of the enclosure of actual circuit-breaking parts to withstand the heaviest stresses likely to occur on breaking short-circuit currents.

He saw no limitation to the use of armour-clad gear for any size of plant or for any voltage, and there were no difficulties which experience to date had brought to light, which are not equally applicable to other forms of switchgear construction.

INSTITUTION NOTE.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH FOR GREAT BRITAIN AND IRELAND.

A deputation from the Board of Scientific Societies, on which the Institution is represented, waited on Lord Crewe, then Lord President of the Council, on the 1st December, 1915, to urge the importance of increased grants for scientific and industrial research.

Lord Crewe informed the deputation that the Government had decided to establish, in place of the Advisory Council for Scientific and Industrial Research, a new and separate administrative Department, to be presided over by the Committee of the Privy Council for Scientific Research and therefore under the control of the President of the Council. He also stated that the Chancellor of the Exchequer was prepared to advise the Government to devote a very large sum for purposes of research.

It has since been announced officially that, subject to the consent of Parliament, the Government have decided to place a large sum of money at the disposal of the new Department to be used as a fund for the conduct of research for the benefit of the national industries on a co-operative basis.

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PRINCIPLES INVOLVED IN COMPUTING THE DEPRECIATION OF PLANT.

By F. GILL and W. W. COOK, Members.

(*Paper received May* 17, 1916; *read before* THE INSTITUTION 11 *January*, *before the* SCOTTISH LOCAL SECTION 9 *January*, *before the* YORKSHIRE LOCAL SECTION 10 *January*, *before the* MANCHESTER LOCAL SECTION 16 *January*, *and before the* BIRMINGHAM LOCAL SECTION 17 *January*, 1917.)

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It is not very satisfactory that engineers should hold such divergent views on so important a question as depreciation.

Possibly this is due to the subject being regarded as one for the accountant alone, but in our view depreciation concerns the engineer, the financier, and the accountant, and no one of the three is competent to settle the question in any particular case, as, in order to obtain correct results, there must be co-operation between the three.

Whilst this is true in the application of the principles, it is also true that each of the three parties concerned must study the question in all its bearings, and it is just as important that the engineer should understand the financial aspect as it is for the others to follow the engineer's methods in his share of the work.

The depreciation component of cost is very often a dominating one, and it is surely illogical to leave this matter in its present unsatisfactory position while devoting time and money to investigating questions which have far less effect on the total cost.

We can discover no reason why there should not be general agreement on this question, it is so largely a question of fact, and because it is possible to demonstrate the correctness or otherwise of any system, there seems no justification for resorting to mere assertion and appeal to authority in support of any particular theory.

There is no difference of opinion as to the importance of the subject and the necessity for making some provision for depreciation. All plant has a limited life; at the end of its life it is worth nothing except the value of the material as scrap, and it is clear that, from the moment it is first brought into use to the end of its life, a process of diminution in value is going on continuously.

Although much has been written on this subject, the only points on which all the writers are agreed are that:—

(*a*) The matter is one of great importance.
(*b*) The term "depreciation" is loosely employed, and has various meanings.

A good deal of trouble has been caused by not strictly defining the scope of the subject under discussion, and misunderstandings may be avoided in the present instance if it is made clear at the outset that by the term "depreciation" is intended to be covered: (1) Provision for the diminution in value of plant in place and working (that is, its loss in value to the owner as a continuing plant), by reason of causes *outside* his control, such as age, wear, and accidents; this provision is hereinafter called "renewals." (2) Provision to enable the owner to take plant out of commission before its physical life is exhausted in cases where, from either progress of the art or growth of the business, it is economically advisable to do so (that is, by reason of causes *within* his control); this provision is hereinafter called "improvements."

It should be noted that the expression "renewals" denotes provision in respect of actual expired capital outlay, [illegible] still variable.

[illegible] any setting up [illegible] plant or for any [illegible] difference in [illegible] standard rates can [illegible]

While saying this, however, it must be made plain that [illegible] remain fixed even though the application of those unvarying principles under different conditions produce varying results.

[illegible] will be found to lead naturally to the financier's and the accountant's view-points also.

The function of the engineer in this matter is to provide [illegible] cost, residual value, and life.

The function of the financier is to provide information regarding the money, the amount available, the rate at which it can be borrowed, and the rate that can be obtained for the loan of it.

The function of the accountant is to provide accurate records based on the decisions arrived at and to see that the real results are neither disguised nor hidden.

All three must come to a common decision and each in any calculations he has to make must work to it, otherwise nothing but chaos can result.

[illegible] regarded as almost entirely an accountant's question, to be brought into [illegible] undertaking may be appropriated as profits. But depreciation is very important long before this stage is reached, and it is because of the great difference in opinion between engineers themselves, as well as between them and financiers and accountants, that this paper is written, in the hope that some agreement, or at any rate, some clear views of the different opinions held, will emerge from the discussion.

[illegible]

When preparing a specification for plant to achieve certain definite results, there is usually more than one way of arriving at the desired end, and skilful judgment in the selection from among the alternatives must be exercised.

[illegible]

[illegible] the duty of studying these costs in [illegible]

[illegible]

It may be advantageous to spend extra capital to obtain low annual charges in respect of one portion of the plant and deliberately to incur high annual charges by reducing capital expenditure on another portion.

Again, it sometimes happens that even the annual charges of the whole plant will not furnish the desired criterion since they are not the same for each year, and in those cases they must of course be brought to some common time-base.

ANNUAL CHARGES.

Annual charges are composed of four principal parts :—

(1) Return on capital outlay, treated as a charge because no engineer, unless in special circumstances, is justified in putting down plant which will not pay a return on its own capital. Even in cases where a return on the outlay is not looked for, the nominal interest is a measure of the burden.
(2) Depreciation—as already defined on page 137.
(3) Maintenance, the cost of keeping the plant in as good condition as is desirable, but not of renewing it.
(4) Operation—the cost of working the plant.

The first three enter into the annual charges of all plant, the fourth does not; for example, a boiler or a tramcar requires to be operated before it can perform its function, but this does not apply to a pole.

Assume a situation in which there is as yet no plant installed and let there be two alternative ways of achieving the results required, A and B as below :—

	Alternative A	*Alternative B*
	First Cost [illegible]	First Cost, £15,000
Annual charges—	£	£
Return on capital ...	500	[illegible]
Depreciation ...	[illegible]	[illegible]
Maintenance ...	500	[illegible]
Operation ...	[illegible]	[illegible]
	[illegible]	2,100

Annual charges for A = £[illegible]
B = £2,100

[illegible] more capital, yet it is worth while to expend the greater sum because the annual charges are less, so that either a reduced sum can be asked for the product, or, since the results achieved are the same, the cash for the product can be the same and an excess profit made.

At this stage it is desirable to insist upon the importance of the utmost accuracy in the preparation of the annual [illegible] they must be accurately founded. When it is remembered [illegible] the engineer by their means to select plant wisely, and so to plan economically, it will be acknowledged that he must use his best endeavours to arrive at annual charges [illegible]

[illegible] charges, they must be the true annual charges, and one cannot express these by the single statement that they are, say, 14 per cent per annum of first cost, unless either the cost is uniform each year, or the rate mentioned is an equated rate taken over the prospective life of the plant.

With reference to uniformity :—

Return on capital.—The amount will be uniform if the capital has not been written down, that is, if the sums put aside for depreciation are kept in a separate fund until the sum that is required has been accumulated. If, on the other hand, part of the capital is paid off each year, the sum for return will decrease each year.

Depreciation.—Here again, the amount required will vary according to the method of making provision and to the treatment of the capital account.

Maintenance.—For the present, let it be assumed that this is constant each year. This point will be returned to later.

Operation.—This is also taken as constant.

It is seen then that the sums required for return on capital and depreciation both depend upon the treatment of the capital account and the depreciation fund ; in fact, these two are so intimately connected that their costs cannot be treated independently.

Lives, Physical and Economic.

For the purpose of this paper there are two lives which must be defined :—

(*a*) Physical Life, that is, the period during which the plant would continue to perform satisfactorily the service to which it is adapted, if allowed to do so, but subject to all causes *outside* the control of the owner, such as wear and tear or accidents.

(*b*) Economic Life, that is, the period of physical life shortened by causes *within* the owner's control, such as desire for economy, improvement of service, the taking out of plant because a greater capacity is required.

It is necessary to distinguish quite clearly between these two. The physical life affects the amount to be put aside each year for renewals, and since by definition the plant can perform its service satisfactorily during the whole time, there is no compulsion to renew before the conclusion of the physical life.

The renewals fund thus ensures that the money invested in plant is always represented by the assets, provided that none of it is voluntarily destroyed.

In the conduct of a business, however, it is often desirable, in the interests of shareholders and consumers alike, to take plant out of commission before the end of its physical life, either because more economical plant is available or because it is no longer capable of meeting new developments of the business.

Since the main cause for these changes is economy, it may be argued that the cost of making them should be defrayed by new capital ; but this is not always available, and if this course were adopted the new capital would not be represented by assets until the new plant had earned enough extra profit to pay for the wastage.

In order that the owner of the plant may be always in a position to take advantage of developments and still be in a sound position, it is necessary to have a special fund available for the purpose, and such a fund is referred to in this paper as the improvements fund.

As such a fund is necessary for the successful conduct and progress of the business, the annual contributions are, in a continuing business, part of the annual charges against the plant.

The distinction between the renewals fund and the improvements fund must constantly be borne in mind.

The charges to the renewals fund represent actual expired capital outlay each year, and consequently are the measure of the diminution of the value of the plant in place considered as a structure, whilst the improvements fund enables plant to be superseded before its physical life is ended, and ensures that when this is done the value of the assets shall always represent the invested capital.

In a change of ownership where it is a condition that the purchaser should take over the plant as a structure, and the valuation is to be on the basis of physical life, any balance which stands to the credit of the improvements fund represents a reserve out of profits which has not been required and belongs to the seller, but if the business is purchased as a going concern, the desirability of superseding plant in the near future may be one of the factors determining the price, in which case it will be necessary to bring the improvements fund into account.

Method of Arriving at Provision for Renewals and Improvements.

Looking first at renewals, what change has occurred in plant which causes it to diminish in value from 100 per cent when it is new, to, say, 10 per cent at the end of its physical life ?

If one takes one of the simplest possible structures, a creosoted telephone pole, and examines it, say, 5 years after erection, one cannot say positively that either its weight or strength is less, as there is no perceptible decay in most cases, nor can one say that it is earning less, as it will frequently be earning a larger sum per annum than at first because carrying more wires.

In fact the only solid ground for saying its value has decreased is that it is 5 years nearer to the end of its life, and the question is how to find the diminution in value caused by the passage of these 5 years.

The methods of arriving at the deduction to be made for any plant which has already been in existence some time may be divided into two classes :—

(*a*) Based on a detailed examination of the plant and an individual assessment of values for each item.

(*b*) Based on an estimated life which the various classes of plant will have under a given standard of maintenance, and providing for the diminution in value by writing off or setting aside a proper sum in respect of each expired year (or other portion) of life.

When carefully examined there is really no sharp dividing line between these two methods.

In the case of detailed examination (*a*), proper weight can be given to condition, but physical examination alone will not enable a proper deduction to be made for the depreciated state of the plant. In some cases, for some years, the plant shows no sign of wear or decay, yet obviously some provision ought to be made for the expired life during those years.

It is usual, therefore, and necessary, to estimate the first cost, life, age, and residual value.

If individual items of plant are dealt with, the life and sometimes the age can only be judged very approximately.

If a [illegible] method of the bulk is considered instead of the individual items, the life and age can be estimated with much greater certainty, while consideration of the amount spent on repairs and upkeep, supplemented by inspection, will give the condition.

While expert examination has a proper and most useful sphere in all cases, and is almost essential in determining the economic life, there is no means whereby one can examine plant and by that examination alone estimate what is the value remaining in the plant in place; some method of computation must be adopted.

The measurement of the effects of wear and tear and the passage of time is essentially a financial operation, and no satisfactory solution can be found without going through the steps of establishing the first cost, residual value, life, and age.

It is often said that one cannot say how long a certain plant will last; but this is not a sufficient answer. One must estimate the life if there is to be any attempt towards scientific treatment in planning.

One cannot neglect capital charges, i.e. return on capital and provision for depreciation; and the latter depends very largely upon life.

Those who say the life cannot be estimated and take, say, 10 per cent as capital charges, do, in fact, estimate the life though they do not state the period, and they do so without taking the necessary precautions to estimate it correctly, because for any particular rate of return on money and with a given residual value, 10 per cent per annum can only be arrived at by one definite life.

Further, without estimates of lives one cannot logically arrive at one common rate for capital charges for various classes of plant capable of living for various periods. It follows, therefore, that of necessity estimates of life must be made.

In the case under discussion, no plant has yet been constructed, so that an examination of the actual conditions is impossible in forecasting the annual charges.

Having discussed the questions of physical and economic lives, it seems advisable to turn first to the method of treating the provision for the capital portions of annual charges based on the economic life, and afterwards to the proportion chargeable to renewals and the calculation of the value of plant in place, based on the physical life.

Most of the examples in the paper which concern economic life have been worked out on a basis of:—

First cost	£100
Residual value	13 %
Economic life	19 years

and the examples which concern physical life on a basis of:—

First cost	£100
Residual value	[illegible]
Physical life ...	[illegible] years

In both cases interest where taken is at 5 per cent per annum. The tables are merely illustrative and the principles involved are as easily discussed on these figures as on any other, and there is some advantage to be gained by keeping the tables for economic and physical lives quite distinct in the discussion.

We suggest that it will be an advantage if those contributing other tables will, unless there are reasons to the contrary, use the same figures.

In discussing these principles, the aim is to ascertain as precisely as possible the proper annual charge against each unit of plant for each year of its life, and thus each unit of plant may be considered as a person who takes service from a public utility company under the condition that he is to be charged a proper rental which shall be exactly sufficient to safeguard the company against all proper charges and give a stated return on the capital employed.

Let the essential conditions be that the plant (or person) shall be charged with a yearly sum sufficient to:—

(1) Pay for all maintenance.
(2) Pay all operating expenses.
(3) At the end of the physical life, renew the capital outlay on it.
(4) Provide sufficient money to enable the company to take advantage of improvements in the art and take out of commission, when desirable, plant which still has some years of life left in it.
(5) Pay the company an agreed return on the money invested, say 5 per cent per annum.
(6) Let it be also assumed that the capital is £100, and that it and the plant do not increase during the whole time.

The problem then is to find how much should the plant or person contribute each year:—

(1) *Maintenance.*—For the moment this charge is assumed to remain constant and can therefore be neglected.
(2) *Operating.*—This is assumed to remain constant and can also be neglected.
(3)-(4) *Renewals and improvements.*—These involve the question of life and residual value. Assume the economic life is agreed at 19 years and that the residual value at the end of the life is 13 per cent of the first cost after paying for cost of recovery.
(5) *Return on capital.*—This needs no discussion.
(6) *Fixed capital and plant.*—This is assumed so that a steady base may be taken throughout.

It must also be laid down what is to be done with the money received each year in advance for renewals and improvements. Everyone agrees it cannot remain idle. It cannot be invested in the business because by hypothesis (6) the size of the plant and the amount of the capital account are fixed; it must therefore be used to repay the capital gradually, or be lent at interest to someone outside the business. Assume that in the latter case it obtains the same rate as that which is agreed upon for return on capital, say 5 per cent per annum.

Since the matter can be treated in different ways, it is necessary to consider what tests shall be required of the various methods. There are two: (1) the total cost of all the annual charges for the economic life of the plant shall not exceed the real cost; and (2) the incidence of the annual charges shall not be such as to cause anomalies in the conduct of the business in different years or periods, unless such incidence is due to some plant condition.

In the typical methods to be examined it is assumed that the first cost is £100, the residual value at the end of the economic life £13, and the economic life 19 years. The total cost is therefore the return on the invested capital during the 19 years and £87 at the end of the 19th year. The simplest way to assess the whole transaction is to take the present value of all payments, and using the assumed rate of interest—5 per cent per annum—it is found, apart from any particular method, that what is required is:—

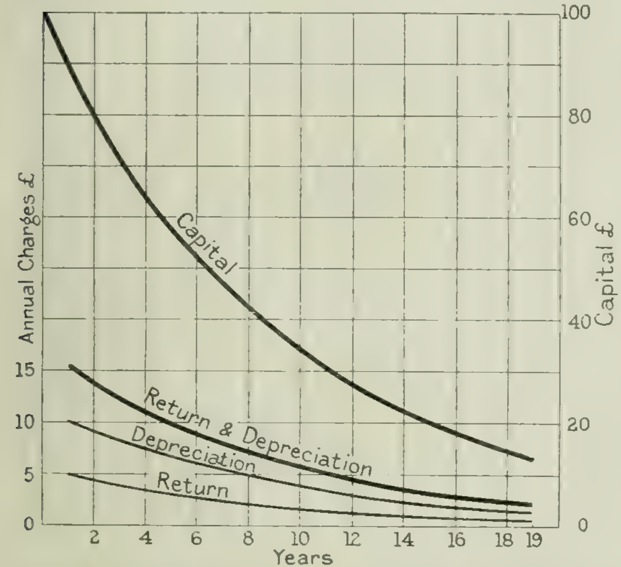

FIG. 1.—Annual Charges. Reducing Balance Method (see Table 1).

The present value of 19 annual payments, of £5 each
for return on capital of £100 = 5 × 12·08532 = £60·43
The present value of £87 required 19 years hence
= 87 × 0·39573 = 34·43
£94·86

This present value, £94·86, is then the total cost, independent of any method, to be used in the first test of any method.

There are various methods of treating the provision for depreciation, but substantially they reduce to the following:—

(1) Maintenance Method, wherein no regular sum is put aside, the plant being maintained and renewed out of revenue expenditure.

(2) Reducing Balance Method, wherein a uniform percentage is deducted each year off the reduced capital cost.

(3) That usually called the Straight Line Method, wherein the annual charge is the ratio of one year to the total time or life.

(4) Sinking Fund or Annuity Method, wherein value is given to the interest the fund will earn until it is wanted.

(1) The Maintenance Method affords no means of calculation, it is bound to be irregular, and since no charge can be made until a renewal actually takes place, the method is always in arrear unless and until a complete renewal is effected.

(2) The Reducing Balance Method is very frequently employed to ascertain the amount to be allocated for depreciation at the end of a year. The first cost being assumed at £100, the residual value 13 per cent, the economic life at 19 years, it will be necessary to apply a rate of 10·18 per cent per annum to the reduced balance to extinguish the £87 during the life, and the costs for return and depreciation are shown in Table 1 and Fig. 1.

TABLE 1.—ANNUAL CHARGES.

Reducing Balance Method.

First Cost = £100. Residual Value = £13. Economic Life = 19 years.

Return on Capital 5 per cent per annum.

A	B	C	D	E	F
End of Year	Capital	Return on Capital 5 % p.a.	Depreciation = 10·182 % p.a.	Total C + D	Amount of Capital Repaid
	£	£	£	£	£
1	89·82	5·00	10·18	15·18	10·18
2	80·67	4·49	9·15	13·64	19·33
3	72·46	4·03	8·21	12·24	27·54
4	65·08	3·62	7·38	11·00	34·92
5	58·45	3·25	6·63	9·88	41·55
6	52·50	2·92	5·95	8·87	47·50
7	47·15	2·63	5·35	7·98	52·85
8	42·35	2·36	4·80	7·16	57·65
9	38·04	2·12	4·31	6·43	61·96
10	34·17	1·90	3·87	5·77	65·83
11	30·69	1·71	3·48	5·19	69·31
12	27·56	1·53	3·13	4·66	72·44
13	24·75	1·38	2·81	4·19	75·25
14	22·23	1·24	2·52	3·76	77·77
15	19·97	1·11	2·26	3·37	80·03
16	17·94	1·00	2·03	3·03	82·06
17	16·11	0·90	1·83	2·73	83·89
18	14·47	0·81	1·64	2·45	85·53
19	13·00	0·72	1·47	2·19	87·00
Total	...	42·72	87·00	129·72	—

Present value of all annual payments (£129·72) = £94·86.

This method results in a relatively heavy charge in the early years and a very light one in the last years. The present value of the whole series of payments is £94·86, and so this method satisfies the check as to total cost; there only remains the check on incidence.

(3) The Straight Line Method has been strongly advocated and requires extended consideration.

Assuming the same case as before (First cost, £100; residual value, £13; economic life, 19 years), £87 is required in 19 years for renewal of plant or redemption of capital.

TABLE 2.—ANNUAL CHARGES.

Straight Line Method as frequently Posed.

First Cost = £100. Residual Value = £13. Economic Life = 19 years.

Repairs on Capital 5 per cent per annum.

A	B	C	D	E	F
End of Year	Capital	Return on Capital 5 per cent	Depreciation p.a.	Total C + D	Total in Depreciation Fund
	£	£	£	£	£
1	100	5	4·58	9·58	4·58
2	100	5	4·58	9·58	9·16
3	100	5	4·58	9·58	13·74
4	100	5	4·58	9·58	18·32
5	100	5	4·58	9·58	22·90
6	100	5	4·58	9·58	27·48
7	100	5	4·58	9·58	32·06
8	100	5	4·58	9·58	36·64
9	100	5	4·58	9·58	41·22
10	100	5	4·58	9·58	45·80
11	100	5	4·58	9·58	50·38
12	100	5	4·58	9·58	54·96
13	100	5	4·58	9·58	59·54
14	100	5	4·58	9·58	64·12
15	100	5	4·58	9·58	68·70
16	100	5	4·58	9·58	73·28
17	100	5	4·58	9·58	77·86
18	100	5	4·58	9·58	82·44
19	100	5	4·58	9·58	87·02
Total		95	87·02	182·02	—

Present value of all annual payments (£182·02) = £115·77.

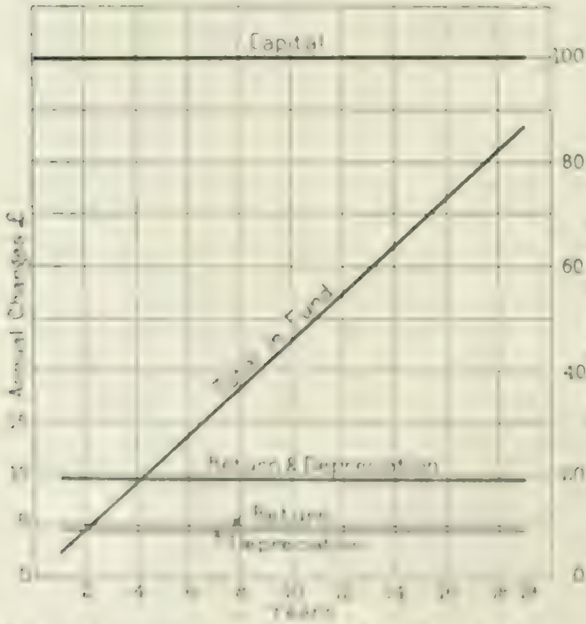

FIG. 2.—Annual Charges—Straight Line Method as frequently Posed (see Table 2).

The straight line method, as usually posed, is simplicity itself. £87 is to be found in 19 years; therefore all that is required is £4·58 per annum for depreciation and, with £5 for return the total charges for these two heads are £9·58 per annum as shown in Table 2 and Fig. 2.

This table does not, however, pass the test of total cost; the present value of 19 annual payments of £9·58 each at 5 per cent. is—

	£115·77
instead of	£94·86
an excess of	£20·91

If £4·58 be set aside annually, there will of course be £87 accumulated at the end of the 19 years; but since it is not prudent to leave money idle, it is plain that interest ought to be, and will be, earned by the money so set aside annually.

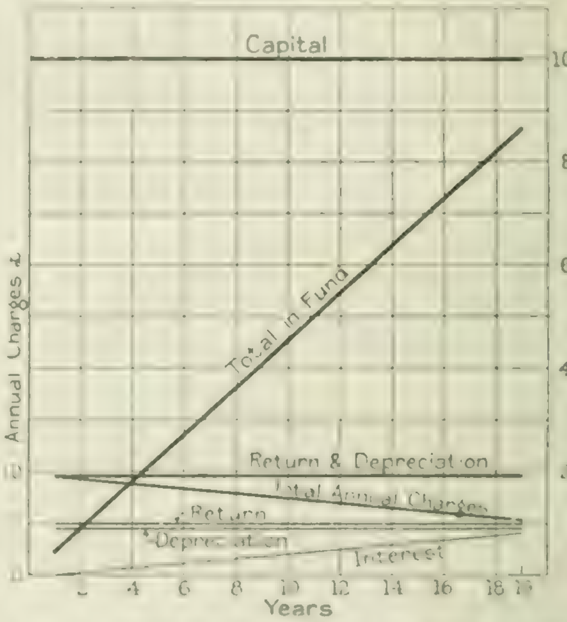

FIG. 3.—Annual Charges—Straight Line Method in Practice (see Table 3).

If interest is taken at 5 per cent per annum and added to the growing fund, there will be at the end of the 19 years not the £87 required, but £139·84, so the yearly payments must be reduced below £4·58 per annum until the amount is just sufficient to accumulate only the £87 required, and this needs a yearly payment of £2·85 for the 19 years.

If the earned interest be not added to the fund, but credited to the general revenue account, as is generally the practice of those who uphold the straight-line method, the effect is that the revenue is increased thereby, with the result that a higher return on the capital is obtained, the interest earned by the depreciation fund not being required for the plant. But this is a violation of the hypothesis, because a stated return on capital was to be earned, no more and no less.

This case is shown in Table 3 and Fig. 3. Here, again, the present value of all the payments exacted for the plant is too great, being £[illegible].

Testing the argument as already suggested in the light of the payment a consumer is to make, it is at once seen that if he pays the £5 + £4·58 each year, then, under the guise of annual charges, he is paying such a sum as will in fact provide the company with a higher return than allowed for by the hypothesis. Column J shows that the total return on capital increases yearly from 5 per cent per annum to 9·12 per cent per annum.

If the straight line law is followed, but instead of accumulating a fund the capital is partly repaid each year, the present value is seen to be correct at £94·86 and there remains the question of incidence.

Table 4 and Fig. 4 show this.

(4) Annuity Method. Table 5 and Fig. 5 show the same case treated as an annuity, by which each year a part of the capital is repaid and a return is paid on the capital outstanding.

Here the total annual charge is uniform at £7·85 per annum, made up of the decreasing return component and an increasing depreciation component. At the end of the life all the capital has been repaid, except £13 which will be found by the sale of the plant. The plant (or consumer) gets the benefit of interest, because as capital is repaid the return thereon ceases. The present value of the series of payments is £94·86.

(4) Sinking Fund Method. Table 6 and Fig. 6 show the case treated by a sinking fund; in this instance the capital remains fixed at £100 and a fund is built up gradually against the end of life, at which time, and not until then, the money will be required either to repay the capital or to replace the plant.

Here the total annual charge is uniform at £7·85 per annum, made up of uniform charges each year both for return and for depreciation. The present value of the series of payments is £94·86.

The depreciation fund is not required until the end of the life, and, of course, earns interest in the meanwhile; this interest is earned by the money contributed by the plant (or person) and must somehow be credited to its source. In this instance the interest is added to the fund and because of that addition the annual charges are reduced.

The advocates of the straight line method have to choose between Tables 2, 3, and 4.

They cannot adopt Table 2, because that requires either that no interest is earned by the money paid annually in advance, or that interest is earned but not disclosed, each being an untenable position.

They cannot adopt Table 3, because that requires the plant (or person) to pay an enhanced annual charge under

TABLE 3.—ANNUAL CHARGES.

Straight Line Method in Practice.

First Cost = £100. Residual Value = £13. Economic Life = 19 years.

Return on Capital 5 per cent per annum.

A	B	C	D	E	F	G	H	J
End of Year	Capital	Return on Capital 5 % p.a.	Depreciation = £4·789 % p.a.	Total C + D	Total in Depreciation Fund	Interest earned by Fund at 5 % p.a.	Total Charges less Interest, E − G	C + G, Return on Capital (incl. Interest)
	£	£	£	£	£	£	£	£
1	100	5	4·58	9·58	4·58	—	9·58	5·00
2	100	5	4·58	9·58	9·16	0·23	9·35	5·23
3	100	5	4·58	9·58	13·74	0·46	9·12	5·46
4	100	5	4·58	9·58	18·32	0·69	8·89	5·69
5	100	5	4·58	9·58	22·90	0·92	8·66	5·92
6	100	5	4·58	9·58	27·48	1·14	8·44	6·14
7	100	5	4·58	9·58	32·06	1·37	8·21	6·37
8	100	5	4·58	9·58	36·64	1·60	7·98	6·60
9	100	5	4·58	9·58	41·22	1·83	7·75	6·83
10	100	5	4·58	9·58	45·80	2·06	7·52	7·06
11	100	5	4·58	9·58	50·38	2·29	7·29	7·29
12	100	5	4·58	9·58	54·96	2·52	7·06	7·52
13	100	5	4·58	9·58	59·54	2·75	6·83	7·75
14	100	5	4·58	9·58	64·12	2·98	6·60	7·98
15	100	5	4·58	9·58	68·70	3·21	6·37	8·21
16	100	5	4·58	9·58	73·28	3·43	6·15	8·43
17	100	5	4·58	9·58	77·86	3·66	5·92	8·66
18	100	5	4·58	9·58	82·44	3·89	5·69	8·89
19	100	5	4·58	9·58	87·02	4·12	5·46	9·12
Total	...	95	87·02	182·02	—	39·15	142·87	—

Present value of all annual payments (£182·02) = £115·77
Less interest (£39·15) = £20·91

£94·86

TABLE 4.—ANNUAL CHARGES.

Straight Line Method. [illegible] of Capital refunded each Year.

First Cost = £100. Residual Value = £13. Economic Life = 19 years.

Return on Capital 5 per cent per annum.

A	B	C	D	E	F
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	£	£	£	£	£
1	95·42	5·00	4·58	9·58	4·58
2	90·84	4·77	4·58	9·35	9·16
3	86·26	4·54	4·58	9·12	13·74
4	81·68	4·31	4·58	8·89	18·32
5	77·10	4·08	4·58	8·66	22·90
6	72·52	3·86	4·58	8·44	27·48
7	67·94	3·63	4·58	8·21	32·06
8	63·36	3·40	4·58	7·98	36·64
9	58·78	3·17	4·58	7·75	41·22
10	54·20	2·94	4·58	7·52	45·80
11	49·62	2·71	4·58	7·29	50·38
12	45·04	2·48	4·58	7·06	54·96
13	40·46	2·25	4·58	6·83	59·54
14	35·88	2·02	4·58	6·60	64·12
15	31·30	1·79	4·58	6·37	68·70
16	26·72	1·57	4·58	6·15	73·28
17	22·14	1·34	4·58	5·92	77·86
18	17·56	1·11	4·58	5·69	82·44
19	12·98	0·88	4·58	5·46	87·02
Total		55·85	87·02	142·87	

Present value of all annual payments £142·87 = £[illegible].

TABLE 5.—ANNUAL CHARGES.

Annuity Method.

First Cost = £100. Residual Value = £13. Economic Life = 19 years.

Return on Capital 5 per cent per annum.

A	B	C	D	E	F
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	£	£	£	£	£
1	97·15	5·00	2·85	7·85	2·85
2	94·16	4·86	2·99	7·85	5·84
3	91·02	4·71	3·14	7·85	8·98
4	87·72	4·55	3·30	7·85	12·28
5	84·26	4·39	3·46	7·85	15·74
6	80·62	4·21	3·64	7·85	19·38
7	76·81	4·04	3·81	7·85	23·19
8	72·80	3·84	4·01	7·85	27·20
9	68·59	3·64	4·21	7·85	31·41
10	64·17	3·43	4·42	7·85	35·83
11	59·53	3·21	4·64	7·85	40·47
12	54·66	2·98	4·87	7·85	45·34
13	49·54	2·73	5·12	7·85	50·46
14	44·17	2·48	5·37	7·85	55·83
15	38·53	2·21	5·64	7·85	61·47
16	32·61	1·93	5·92	7·85	67·39
17	26·39	1·63	6·22	7·85	73·61
18	19·86	1·32	6·53	7·85	80·14
19	13·00	0·99	6·86	7·85	87·00
Total		62·15	87·00	149·15	—

Present value of all annual payments £149·15 = £94·86.

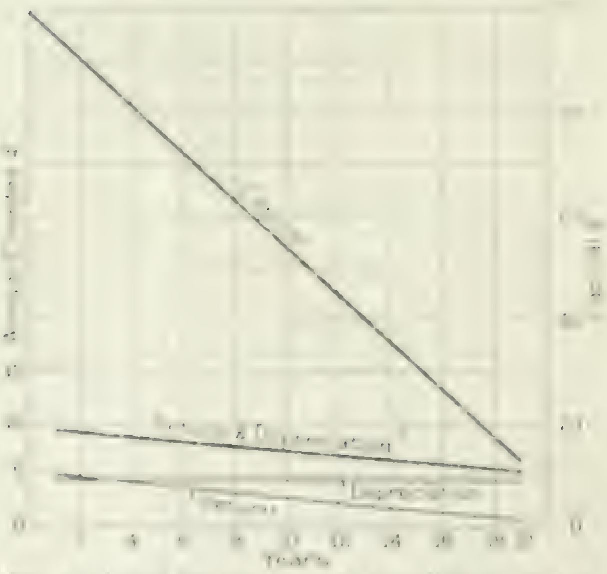

FIG. 4.—Annual Charges. Straight Line Method. [illegible] Table 4.

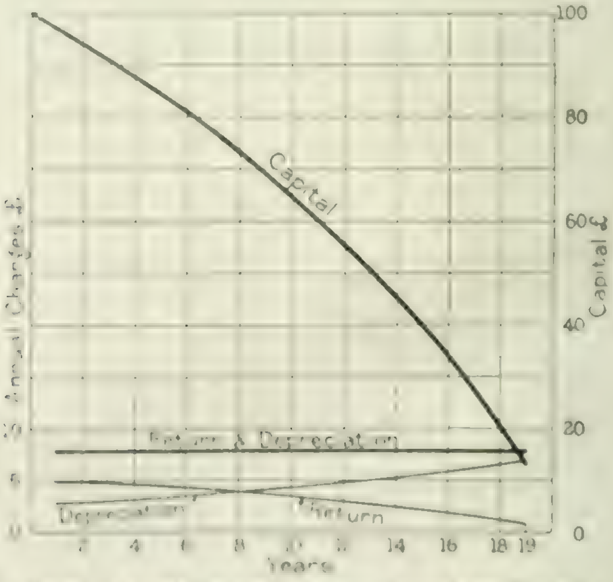

FIG. 5.—Annual Charges. Annuity Method see Table 5.

[illegible]

They are not likely to adopt Table 4, because that [illegible] charge which reduces each year till the end of the life of each portion of plant and then increases and

TABLE 6.—ANNUAL CHARGES.

Sinking Fund Method.

First Cost = £100. Residual Value = £13. Economic Life = 19 Years.

Return on Capital 5 per cent per annum.

A	B	C	D	E	F	G
End of Year	Capital	Return on Capital 5 % p.a.	Depreciation = £2·8488 % p.a.	Total C + D	Interest Earned by Fund at 5 % p.a.	Total Amount in Depreciation Fund
	£	£	£	£	£	£
1	100	5	2·85	7·85	—	2·85
2	100	5	2·85	7·85	0·14	5·84
3	100	5	2·85	7·85	0·29	8·98
4	100	5	2·85	7·85	0·45	12·28
5	100	5	2·85	7·85	0·61	15·74
6	100	5	2·85	7·85	0·79	19·38
7	100	5	2·85	7·85	0·96	23·19
8	100	5	2·85	7·85	1·16	27·20
9	100	5	2·85	7·85	1·36	31·41
10	100	5	2·85	7·85	1·57	35·83
11	100	5	2·85	7·85	1·79	40·47
12	100	5	2·85	7·85	2·02	45·34
13	100	5	2·85	7·85	2·27	50·46
14	100	5	2·85	7·85	2·52	55·83
15	100	5	2·85	7·85	2·79	61·47
16	100	5	2·85	7·85	3·07	67·39
17	100	5	2·85	7·85	3·37	73·61
18	100	5	2·85	7·85	3·68	80·14
19	100	5	2·85	7·85	4·01	87·00
Total ...		95	54·15	149·15	32·85	—

Present value of all annual payments (£149·15) = £94·86.

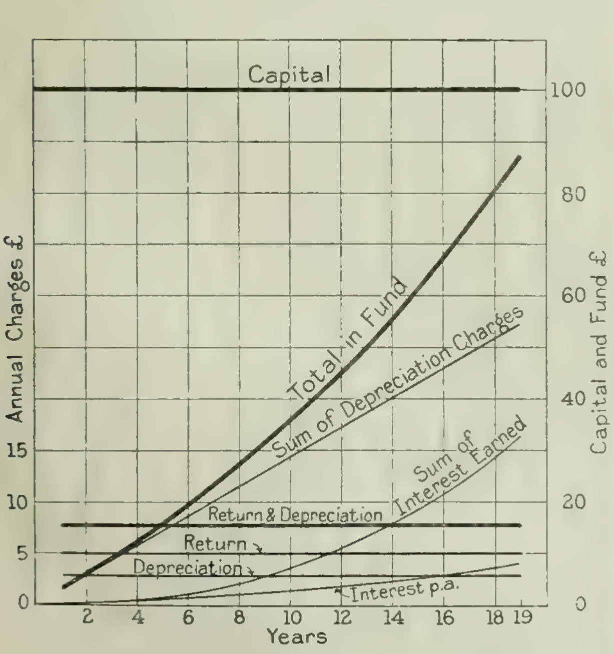

FIG. 6.—Annual Charges. Sinking Fund Method (see Table 6).

again commences to fall. It would be impracticable to base any rates on this table.

Tabulating the present values of the whole transaction by the various methods, we have Table 7.

TABLE 7.

Present Value of the Annual Charges for 19 Years by the Various Methods shown in Tables 1 to 6.

Method	Table No.	Figure No	Annual Charges	Present Value
			£	£
Real requirements ...	—	—	—	94·86
Reducing balance ...	1	1	15·18 to 2·19	94·86
Straight line as frequently posed	2	2	9·58	115·77
Straight line in practice	3	3	9·58	115·77
Straight line if proportion of capital is repaid each year	4	4	9·58 to 5·46	94·86
Annuity	5	5	7·85	94·86
Sinking fund	6	6	7·85	94·86

Now it is obvious that each method produces exactly the required present value, except that which takes up the position that interest will not be earned on the money received each year and in advance of being required, or while admitting that interest will be earned does not credit it to its source.

Examining the methods shown in Tables 1, 4, 5, and 6, each of which has a present value of £94·86, for the test of incidence, Tables 1 and 4 require an annual charge which varies each year, while Tables 5 and 6 have charges which are steady each year.

There is no condition as regards the plant which requires this varying annual charge, and certainly no plant condition which would enable one to distinguish between the varying annual charges in Tables 1 and 4.

If there is some real reason for varying annual charges, of course they must be faced; but if they are untrue it is foolish to cumber a forecast of annual charges with a varying scale.

The reducing balance method (No. 1) is seen to be one of convenience and not of fact, because if it were really correct that the annual charges vary in such a marked fashion, e.g. 1st year 15·18 per cent, 6th year 8·87 per cent, 12th year, 4·66 per cent, then either there must be some counterbalancing increasing cost, or the charge to a consumer for the use of the plant would require to be a reducing one.

There is no such reducing charge in practice; consequently, if the steady charge to the consumer is sufficient to give a return of 5 per cent in the first year, then the same charge will give 15·8 per cent return in the 6th year, 39·3 per cent in the 12th year, and 94·8 per cent in the 19th year.

The same reasoning applies to the method shown in Table 4; in ordinary practice there is no such reducing charge, except in book-keeping, and that has its foundation in convenience or prudence and not in the actual requirements of the plant.

On the other hand both the annuity and sinking fund methods are correct in amount, satisfy all real requirements demanded by the plant, and, being uniform, can be easily handled.

In practice it is not usual to repay the capital fractionally each year; the money set aside for depreciation is generally accumulated until wanted, and the sinking fund method satisfies all conditions of the problem so far.

VALUE OF PLANT IN PLACE AT ANY TIME.

The engineer controlling a system must frequently not only to know the annual charges on each kind of plant, but also to estimate the value remaining in the plant at any time.

In considering replacement of plant, or the adoption of improved plant, it frequently happens that the question arises whether it is economical to take out certain plant still performing satisfactorily the service it is adapted for, and replace it by new plant of a more economical nature. If the existing plant is taken out, there will be a wastage of its then value in place, plus the cost of taking it out and less the amount received for the recovered materials, the net result of this being a present loss when the change is made.

Against this loss there is to be set any economy in annual charges that may be gained by the new plant during the period which would have remained of the displaced plant's life. Further, since the wastage must be incurred when the change is made, while the prospective savings are in the future, the two sums must be brought to a common time for comparison; in fact, the problem is to find out if it is worth while to incur a present loss to achieve a future gain.

Unless the new plant will thus pay for the wastage, or unless there are compelling reasons which require the change irrespective of economy, the change should not be made.

The solution largely depends upon what is the value of the plant in place, still performing its service satisfactorily and capable of continuing to do so for some time longer, and

TABLE 8.—VALUE OF PLANT IN PLACE.

Sinking Fund Method.

First Cost = £100. Residual Value = £2. Physical Life = 25 years.

Return on Capital 5 per cent per annum.

A		B	C	D	E	G	H	L
End of Year								
Successive Ownership	In Plant's Life	Capital	[illegible]	[illegible]	Total C + D	[illegible] Fund	Value of Plant in Place B − G	Per cent Return on Capital
First Owner		£	£	£	£	£	£	
1	1	100·00	5·00	2·05	7·05	2·05	97·95	5
2	2	100·00	5·00	2·05	7·05	4·21	95·79	5
3	3	100·00	5·00	2·05	7·05	6·47	93·53	5
4	4	100·00	5·00	2·05	7·05	8·85	91·15	5
5	5	100·00	5·00	2·05	7·05	11·35	88·65	5
6	6	100·00	5·00	2·05	7·05	13·97	86·03	5
7	7	100·00	5·00	2·05	7·05	16·72	83·28	5
8	8	100·00	5·00	2·05	7·05	19·61	80·39	5
Second Owner								
1	9	80·39	4·02	3·03	7·05	3·03	77·36	5
2	10	80·39	4·02	3·03	7·05	6·22	74·17	5
3	11	80·39	4·02	3·03	7·05	9·56	70·83	5
4	12	80·39	4·02	3·03	7·05	13·08	67·31	5
5	13	80·39	4·02	3·03	7·05	16·76	63·63	5
6	14	80·39	4·02	3·03	7·05	20·64	59·75	5
7	15	80·39	4·02	3·03	7·05	24·70	55·69	5
8	16	80·39	4·02	3·03	7·05	28·97	51·42	5
Third Owner								
1	17	51·42	2·57	4·48	7·05	4·48	46·94	5
2	18	51·42	2·57	4·48	7·05	9·19	42·23	5
3	19	51·42	2·57	4·48	7·05	14·13	37·29	5
4	20	51·42	2·57	4·48	7·05	19·32	32·10	5
5	21	51·42	2·57	4·48	7·05	24·77	26·65	5
6	22	51·42	2·57	4·48	7·05	30·49	20·93	5
7	23	51·42	2·57	4·48	7·05	36·49	14·93	5
8	24	51·42	2·57	4·48	7·05	42·80	8·62	5
Fourth Owner								
1	25	8·62	0·43	6·62	7·05	6·62	2·00	5

the engineer must be able to estimate this value by some logical process.

If the first cost and the annual charges have been rightly estimated, the diminution in value is the amount which should be in the renewals fund, for that was the very purpose of the fund. That is, the first cost less the amount which should be in the fund is the measure of the remaining value; or it may be stated that the remaining value in the plant plus the amount which should be in the renewals fund is always equal to the first cost.

One easy way to test the equity of the value in place produced by the alternative methods used in treating depreciation is to examine how each would result if an undertaking passed successively to several owners, on the basis of the remaining value being the first cost less the amount which should be in the renewals fund.

In this case, as already shown, the life concerned is not the economic life but the physical life, so that in calculating the following tables we must take the physical life of 25 years and the residual value, at the end of life, of £2.

Assume an original owner whose conditions are set out in Table 8 (5 per cent sinking fund), to whom the user of the plant pays £7·05 per annum, sells at the end of the 8th year on the basis of this table. He will then sell for £100 less £19·61 (the amount in the fund), = £80·39.

This second owner's conditions will then be: Capital £80·39, remaining life 17 years, residual value £2, other conditions as before, and the table shows these figures for the next 8 years.

If the second owner transfers to a third owner at the end of the 16th year, on the same basis, he will then sell for £80·39 less £28·97 = £51·42.

The third owner's conditions will then be: Capital £51·42, remaining life 9 years, residual value £2, other conditions as before, and the financial result is shown in the table.

If the third owner transfers to a fourth at the end of

TABLE 9.—VALUE OF PLANT IN PLACE.

Straight Line Method.

First Cost = £100. Residual Value = £2. Physical Life = 25 years.

Return on Capital 5 per cent per annum.

A		B	C	D	E	F	G	H	J	K	L	M
End of Year												
In Different Ownerships	In Plant's Life	Capital	Return on Capital 5 % p a	Renewals Fund	Total C+D	Balance to equalize First Owner's Annual Charge of £8·92 p a	Total in Renewals Fund	Value of Plant in Place, B−G	Interest on Fund	Total Return C+F+J	Per cent Return on Capital	Average per cent Return on Capital
First Owner		£	£	£	£	£	£	£	£	£		
1	1	100·00	5·00	3·92	8·92	—	3·92	96·08	—	5·00	5·00	—
2	2	100·00	5·00	3·92	8·92	—	7·84	92·16	0·20	5·20	5·20	—
3	3	100·00	5·00	3·92	8·92	—	11·76	88·24	0·39	5·39	5·39	—
4	4	100·00	5·00	3·92	8·92	—	15·68	84·32	0·59	5·59	5·59	5·69
5	5	100·00	5·00	3·92	8·92	—	19·60	80·40	0·78	5·78	5·78	—
6	6	100·00	5·00	3·92	8·92	—	23·52	76·48	0·98	5·98	5·98	—
7	7	100·00	5·00	3·92	8·92	—	27·44	72·56	1·18	6·18	6·18	—
8	8	100·00	5·00	3·92	8·92	—	31·36	68·64	1·37	6·37	6·37	—
Second Owner												
1	9	68·64	3·43	3·92	7·35	1·57	3·92	64·72	—	5·00	7·28	—
2	10	68·64	3·43	3·92	7·35	1·57	7·84	60·80	0·20	5·20	7·58	—
3	11	68·64	3·43	3·92	7·35	1·57	11·76	56·88	0·39	5·39	7·85	—
4	12	68·64	3·43	3·92	7·35	1·57	15·68	52·96	0·59	5·59	8·14	8·28
5	13	68·64	3·43	3·92	7·35	1·57	19·60	49·04	0·78	5·78	8·42	—
6	14	68·64	3·43	3·92	7·35	1·57	23·52	45·12	0·98	5·98	8·71	—
7	15	68·64	3·43	3·92	7·35	1·57	27·44	41·20	1·18	6·18	9·00	—
8	16	68·64	3·43	3·92	7·35	1·57	31·36	37·28	1·37	6·37	9·28	—
Third Owner												
1	17	37·28	1·86	3·92	5·78	3·14	3·92	33·36	—	5·00	13·41	—
2	18	37·28	1·86	3·92	5·78	3·14	7·84	29·44	0·20	5·20	13·95	—
3	19	37·28	1·86	3·92	5·78	3·14	11·76	25·52	0·39	5·39	14·46	—
4	20	37·28	1·86	3·92	5·78	3·14	15·68	21·60	0·59	5·59	14·99	15·26
5	21	37·28	1·86	3·92	5·78	3·14	19·60	17·68	0·78	5·78	15·50	—
6	22	37·28	1·86	3·92	5·78	3·14	23·52	13·76	0·98	5·98	16·04	—
7	23	37·28	1·86	3·92	5·78	3·14	27·44	9·84	1·18	6·18	16·58	—
8	24	37·28	1·86	3·92	5·78	3·14	31·36	5·92	1·37	6·37	17·09	—
Fourth Owner												
1	25	5·92	0·30	3·92	4·22	4·70	3·92	2·00	—	5·00	84·46	84·46

[illegible]

[illegible] life 1 year, residual value £2, other conditions [illegible].

This last owner finds £2 from sale of materials and £0·62 from his renewals fund and thus gets back the money he had invested.

It is true that the portion of the annual charge allocated [illegible] the increase is exactly counterbalanced by the reduction of the charge in respect of return on capital, in this case, [illegible]. It will be observed that each successive owner has taken over the plant at what it would have stood at, had part of the capital been paid back each year on the annuity method.

Thus each successive owner has had the same plant, the same annual charge, and has got back all his capital at the end of his term.

Of course if the renewals fund is not credited with the same rate of interest as the return on capital, the strict equality will not hold good, but the only reason for accepting a less rate than the plant earns is to obtain a greater security for the fund than for the main investment, and this course is based on prudence rather than on equity.

Now contrast what happens under the straight line law, the annual rental remaining constant at the amount fixed by the first year's annual charge. The figures used are shown in Table 9.

The first owner's conditions are: First cost £100, life 25 years, residual value £2. He charges the plant with £8·92 per annum and has the plant for 8 years. During that time the money he receives, together with the interest earned by the renewals fund, which is not credited to its source, i.e. the plant account, is sufficient to enable him to pay a return on his capital increasing from 5 to 6·37 per cent.

He then sells on the basis of this table at £100 less £31·36 = £68·64, and thus, with what is in his renewals fund, his capital is repaid.

The second owner's conditions are: First cost £68·64, residual value £2, remaining life 17 years, and the table shows the figures for the next 8 years.

Here it is seen that the annual charges for the second owner consisting of the return, Column C plus the Renewals Column D, fall short of the total for the original owner by £1·57, and this is available with the interest earned by the fund to give a total return on the capital increasing from 7·28 per cent per annum in the 9th year to 9·28 per cent per annum in the 16th year.

If the second owner transfers to a third at the end of [illegible] for this owner will be: First cost [illegible].

[illegible] the total return on the capital increases from 13·41 per cent [illegible].

[illegible] will be: First cost £5·92, residual value £2, remaining life 1 year, and his position is shown in the table.

This last owner gets £2 for the residual value, which with £3·92 in the renewals fund repays his capital, and the total return on his capital is 84·64 per cent per annum.

Thus each successive owner has had the same plant, and has got back all the capital invested, but each successive owner has received a higher percentage return on the capital invested than any of the previous owners.

It may be argued that the amount of profit an owner can make has nothing to do with the value of the plant, and this is true. In the above cases the relative profits under the same conditions have merely been used to test whether [illegible] the plant is valued seems a fair one [illegible] not.

When one finds that on one hand, when interest is brought into the transaction, there is absolute equality as between various years or various owners, and on the other hand, when interest is not brought in, the successive year or successive owner is always progressively favoured, one has good ground for the conclusion that all is not right with the method of valuation which neglects interest on the renewals fund payments.

[illegible] TO SINKING FUND FOR ASCERTAINING THE VALUE OF PLANT IN PLACE

Those who advocate the straight line method, as against the sinking fund, use arguments which group themselves [illegible] the following manner:—

(1) The straight line method has always been adopted in valuations.

(2) If half the life is gone, half the value is gone.

(3) The sinking fund is a wrong method because if a person buys at depreciated value on the sinking fund basis, at the end of the life there is only in the fund the amount the buyer paid and not the cost which then has to be found for the new plant.

(4) The depreciation to be paid to the sinking fund by successive owners is an increasing amount.

(5) The sinking fund method is wrong because it locks up the money required for renewal of the short-lived plant.

(6) The sinking fund method is wrong for plant because the life is uncertain. It is right for a lease or annuity where the life is known.

(7) [illegible] that the rate of interest earned by a redemption fund can affect the value of plant.

(1) This fact in itself is not a sufficient reason. If the [illegible] and if it is right it is surely capable of demonstration.

(2) A dogmatic assertion is not a convincing argument, and here again the claim should be substantiated by proof.

(3) This seems an absurd contention but it has seriously been put forward. It means that if "A" expends £100 on [illegible] depreciated value, say £60, "B" expects to have in his depreciation fund at the end of the plant's life £100 with which to install the new plant then required and not merely the £60 which he gave.

The simplest answer to this is to reduce it to an absurdity.

If "B" buys the plant on its very last legs for 1d., he is to find £100 in the sinking fund when the last moment comes!

In any case this argument would apply to any method of computing depreciation.

(4) This has already been dealt with in Tables 5 and 8, and these show that the increased amount required for redemption is exactly counterbalanced by the reduction in the amount required to pay the same per cent return.

With regard to No. 5, suppose a plant is composed of three classes, sinking fund being used as shown in Table 10.

TABLE 10.

Illustrating Redemption by 5 per cent Sinking Fund of Plant composed of Three Classes as shown.

Class	First Cost	Life	Residual Value	Annual Payment for Renewals.
	£	Years	Per cent	£
A	100	10	Nil	7·95
B	100	5	,,	18·10
C	100	2	,,	48·78
	300	3·75	—	74·83

It is obvious that the amount of £74·83 per annum is correct for the equated life of 3·75 years and is composed of three parts, each for a different life, and that each part will renew its own plant as the time comes. This is shown in Table 11.

TABLE 11.

Illustrating sufficiency of Renewals Fund used in Table 10.

End of Year	Payment to Renewals Fund	Interest earned by Fund	Amount in Fund before renewing	Cost of Renewal and Class renewed	Amount carried forward in Fund
	£	£	£	£	£
1	74·83	—	74·83	—	74·83
2	74·83	3·74	153·40	100 (C)	53·40
3	74·83	2·67	130·90	—	130·90
4	74·83	6·54	212·27	100 (C)	112·27
5	74·83	5·61	192·71	100 (B)	92·71
6	74·83	4·63	172·17	100 (C)	72·17
7	74·83	3·61	150·61	—	150·61
8	74·83	7·53	232·97	100 (C)	132·97
9	74·83	6·65	214·45	—	214·45
10	74·83	10·72	300·00	300 (A, B, C)	—

This table shows that if the sinking fund be correctly founded, the money can be put away into a fund and there will always be sufficient to provide the proper sum for renewals as they come due. The assertion that the money is locked up and cannot be used is untrue.

No. 6 may be stated in another way (but this only applies when part of the life has already expired).

(*a*)	The expired life is, say, ...	20 years
(*b*)	The best estimate of the remaining life is, say, ...	20 ,,
	Making the estimated total life ...	40 years

but (*a*) is certain and (*b*) is uncertain, therefore it is said that there should be some allowance taken off (*b*) for that uncertainty.

It is admitted by some advocates of the straight line method that when the life can be accurately foretold, as in the case of a lease, the sinking fund method of valuation is a correct one; but they say the life of plant is uncertain and cannot be foretold and they therefore value plant by means of the straight line method.

Let us see what result this has in practice. Assume plant 20 years old, which the straight line advocate would value at 50 per cent of first cost; this valuation is arrived at because he believes the plant will have a total life of 40 years. Solely, however, because this is a belief and not a fact he will not use the sinking fund method, admittedly correct for a known life of 40 years, but employs the straight line method which must be incorrect if the plant's life exceeds 30 years. In effect he first makes an estimate of the remaining life and then halves it.

If the estimates of life have been arrived at honestly and with all the available knowledge, there is just as much likelihood that they will be exceeded as that they will not be attained, and it must be just as fair for the seller to make a claim for this uncertainty as it would be for the buyer to do so. The proper time for such questions to be raised is when the lives are fixed, and once this has been done it is not logical for either side to justify an obviously unfair method by saying that it may redress a possible error in figures which have been fixed, when it is just as probable that it will increase the effects of the error.

With regard to No. 7, the authors hold that the valuation of plant is a financial operation and cannot be arrived at by any other means. If that is so, the value of the plant must be affected by the value of money held in advance.

It is recognized that the first cost of the plant depends to some extent on the return which has to be paid for the capital expended, and in the same way there is nothing unreasonable in the interest earned by the renewals fund affecting the value of the plant at any time.

Naturally, the rate of interest and return on capital must be fair and not fanciful, but that only requires the valuer to use fair rates and does not require him to assume an untruth, that the money in the fund earns nothing.

The straight line method appears to rest on two points: (*a*) it is so simple and avoids calculation; and (*b*), the magic of the words, half time, half value!

The simplicity is useless if it is wrong; and that half value is correct at half life has only been asserted and not demonstrated.

EQUATED LIVES FOR COMPLEX PLANT.

In treating a case in which there are various lives, it does not appear to be well known that the average life obtained in the usual manner of getting a weighted average [illegible] of assets. The late Mr. Robert Hammond [illegible] his paper on "Depreciation."

[illegible]

	[illegible]	[illegible]	[illegible]
Class A	[illegible]	10	[illegible]
,, B	[illegible]	[illegible]	1,000
,, C	[illegible]	2	[illegible]
	[illegible]		[illegible]

Total average life [illegible] = 7 years.

But in this calculation, £300 for Class A, £200 for Class B and £100 for Class C were employed, whereas in the complete cycle of 10 years the money actually required will be :—

Class A, [illegible] = [illegible]
,, B, [illegible] = [illegible]
,, C, [illegible] = [illegible]
1,200

[illegible] if interest be not added to the fund :—

	[illegible]	[illegible]	[illegible]
Class A	[illegible]	[illegible]	[illegible]
,, B	[illegible]	[illegible]	2,000
,, C	[illegible]	2	[illegible]
	[illegible]		[illegible]

Equated life = [illegible]

[illegible] without interest, is to divide the first cost by the sum of [illegible]

	[illegible]	[illegible]	[illegible]
Class A	[illegible]	[illegible]	[illegible]
,, B	200	[illegible]	40
,, C	100	[illegible]	[illegible]
	[illegible]		[illegible]

Equated life = [illegible]

[illegible] added to the renewals fund, the calculation will be :—

[illegible]

[illegible]

From these examples it will be seen that we have :—

Average life ...	7	Years
Equated life without interest ...	5	,,
,, ,, 5 per cent p.a. ...	4·05	,,

[illegible] equated life of 5 years without interest, or 4·05 years with 5 per cent interest, will [illegible] to renew each part as its time comes to an end. To use an average life of 7 years by which to calculate the amount required to renew the plant would, however, result in a serious deficit.

In the above example, £1,200 [illegible] being required over the 10 years, the annual instalments and total amount will be :—

First Cost	[illegible]	Annual Instalments	Total Amount in 10 Years
[illegible]	Average 7, no interest	[illegible] = 85·71	857
[illegible]	Equated 5	[illegible] = [illegible]	[illegible]
[illegible]	[illegible] interest	[illegible] + interest	1,200

So that if an average life of 7 years is taken for calculating the provision, the actual deficit will be [illegible] = [illegible] in the 10 years.

[illegible] The equated life is purely a financial period and has nothing directly to do with the life of the plant (though, of course, based upon this). It is the period in which the annual instalments would accumulate to the total required, and that being so, it is of course to some extent dependent upon whether interest is added to the fund or not, because it depends upon the rate of growth.

From this example it will be seen that there is a great danger if the difference between average and equated lives is not appreciated. For a complex plant, use of the average life will result in inadequate provision, because the equated life is always shorter than the average life. Provision for a complex plant can only be made either by providing separately for each part and summating [illegible], or by using the correct equated life and treating the plant as a whole.

[illegible] PLANT

When, however, a subdivision of plant having the same general characteristics is considered, the average lives or ages may safely be used. Assume, for example, that certain pieces of plant all of the same general character, [illegible] that the weighted average duration is 28·75 years.

Obviously all the poles will not live exactly this period; some will die earlier and some live longer, and the question arises whether the average life may be used as the life of the pole, seeing that in the previous case the use of the average life would not provide the necessary money for [illegible]

If the plant considered is all of the same kind, then the [illegible] shows that each sub-class of plant should have very much the same characteristics since its requirements are specified and it is examined for compliance with the specification. It is therefore largely free from what may be termed infantile mortality and from the risks due to a diseased condition; consequently, the mortality instead of being spread all over the whole period ought to be grouped more closely.

Fig. 7 shows an examination of mortality of creosoted wooden poles as recorded by the British Post Office. In this case the ages of 10,662 poles, taken out of service on account of decay, were recorded.

Fig. 7 shows that the most common period is strongly marked, there being 82·6 per cent of deaths within a period, 10 per cent on each side of the average, that is, between 25·9 and 31·6 years.

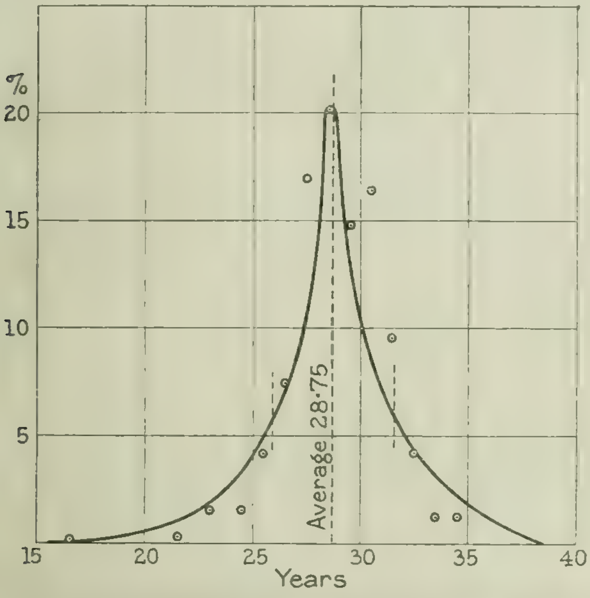

Fig. 7.—Average Physical Lives of 10,662 Creosoted Wooden Poles recorded by the British Post Office.

The period when 50 per cent were dead was 28·65 years. The average weighted life of those poles was 28·75,* and the equated life on a 5 per cent per annum sinking fund is 29 years.

This supports the general reasoning that provided plant is grouped in sub-classes having the same general characteristics the weighted average life of the individual items may safely be used, but groups not having the same general characteristics must be treated separately.

Where Life is limited by Units of Work performed rather than by Time.

In some cases the life of plant is limited by the units of work performed rather than by time. One example of this is a tool such as a lathe or press; another is a locomotive. Such things do not wear out by the passage of time, but by the work which is done by them, and it would be wrong to estimate the life of such a thing merely in years irrespective of work.

The question arises, how the proper charge per unit of work is to be arrived at, since in some cases there must be found the correct amount to be charged to each job for the use of a tool or machine.

In such a case, time, i.e. the physical and economic lives, must be brought into the calculation, and one is bound to estimate a period during which the units of work will be performed in order not to ignore the fact that the payment for depreciation is made in advance of the money being actually required, and therefore interest must accrue.

Example of Lives and Calculations for Renewals and Improvements Funds for Typical Plant Class.

Table 12 gives a detailed example of depreciation charges and shows the provision for renewals fund based upon the physical lives, and the provision for improvements fund based upon the difference between the economic and physical lives for each of the three sub-classes, A, B, and C, of which the plant class is composed.

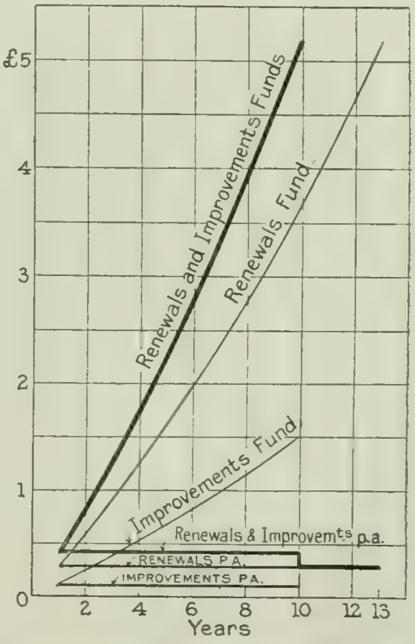

Fig. 8.—Renewals and Improvements for Sub-class C (see Table 12).

Fig. 8 shows the funds for sub-class C only. In this case it will cost more to remove the worn-out plant than the material is worth; consequently the residual value is a minus quantity. The depreciable amount is £5·2 for both the physical and economic lives. The charge for renewals is £0·2936 per annum, and for improvements it is £0·1198 per annum. In 13 years the renewals fund alone will accumulate sufficient to replace the plant, but the assumption is that it will be desirable to take the plant out of commission after 10 years' life, and the improvements fund provides that which the renewals fund then lacks.

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* The authors do not wish to be taken as endorsing this figure, but any discussion on such matters is not germane to the question under consideration.

TABLE 12.

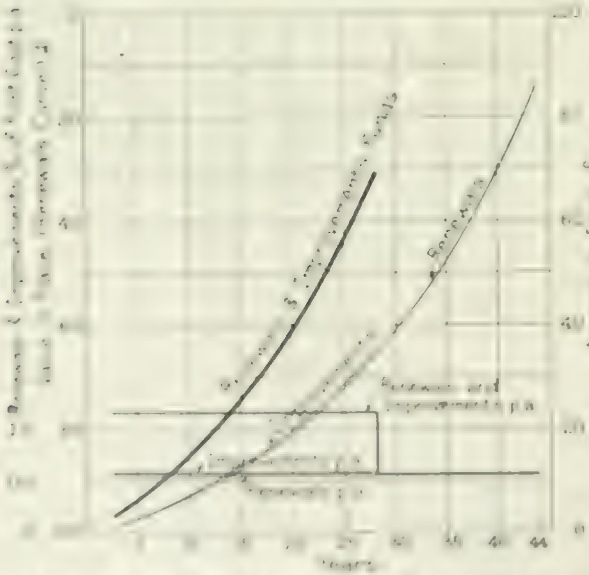
[illegible] 5 per cent Sinking Funds.

[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	
	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P
A	[illegible]	[illegible]	[illegible]	77·4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	[illegible]
B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0·7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−0·2	5·2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43·0	[illegible]	[illegible]	30·2	[illegible]	[illegible]	28·3	[illegible]	1·1711	[illegible]	[illegible]

SUMMARY.

	[illegible]	[illegible]	[illegible]	[illegible]		
				[illegible]	[illegible]	Total
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	13·1	[illegible]	[illegible]		1·1711
[illegible]	[illegible]	[illegible]	69·8		[illegible]	

Fig. [illegible] shows the funds of the three sub-classes together and in this case the equated physical life is [illegible] years and



[illegible]

[illegible] years. [illegible] ably higher than 13·1 per cent at the end of the physical life. The annual contributions to the funds are :—

Renewals fund ... ... [illegible] of first cost
Improvements fund ... [illegible]
Total for depreciation ... [illegible]

The annual charges for capital are therefore :—

	Per cent
Return on capital	[illegible]
Depreciation	[illegible]
Total annual charges for capital ...	6·1711

The provision in these tables is sufficient for the renewal of each part as it becomes due, and nothing in the way of renewals is left to be provided out of maintenance.

CONSTANT MAINTENANCE COST.

On page [illegible] it was assumed that the maintenance cost would be constant throughout the life of the plant, and it is necessary to return to this question.

It was shown in Tables 10 and 11 that the renewal of each part, as it is required in its turn, is provided for by the fund established on the basis of the equated physical life. In the example there given, the shortest life is 2 years and the money necessary to renew those parts is provided for under the method [illegible]. If any portion had a life of [illegible] year, by [illegible] that life into the equated life, provision for its renewal would be assured. It is therefore clear that an equated life arranged for all the plant provides money for the renewal of every part. The cost of maintenance is the cost of looking after the plant, keeping it in running order, repairs, keeping records and inspections, but not of making renewals.

It seems clear from this reasoning that there is not much room for increasing maintenance cost. In the case of cables, for example, when any part goes faulty, if it is a serious matter it requires the renewal of a part of the cable, and in that way the whole cable may be renewed, part at a time, over a period. But each of these renewals is provided for and they do not call for increased maintenance cost. In the same way, if the equated life of a dynamo includes the brushes, when these fail they will be renewed out of the renewals fund and their renewal does not cause any increase in maintenance, and if in a boiler the firebars are included in the equated life, their renewal will not cause any increase to maintenance cost. Sometimes in practice it is found more convenient to charge small renewals to maintenance rather than to renewals account, but that convenience does not affect the question of fact. In the case of a structure where the main cost is due to painting, there is an interval between the times when painting must be done, but there is no increasing frequency of painting as the structure gets older.

The general idea of increased maintenance cost with advancing age appears to have arisen out of the fact that provision has not been contemplated for all renewals in a depreciation scheme, in which case as the renewals come due, of course there will be the increased cost due to them. But as in the analysis set out herein all renewals are included under "renewals," it seems right to say that maintenance cost does not increase with age.

We believe that constant maintenance cost, if full provision is made for renewals, is a tenable assumption.

In the case of telephone plant, careful investigation failed altogether to detect any increase in the cost of maintenance with advancing age, and so far we know of no data which has been put forward showing increasing cost apart from renewals.

If one were trying to make plant last beyond the period during which it would give its service satisfactorily, there might be such a supervision and maintenance cost as would constitute an added burden, but that reason cannot be advanced because it would be a contradiction of the meaning of the term "physical life," which is limited to the period during which the plant can perform its service satisfactorily.

Some advocates of the straight line method say that the interest on the depreciation fund is required to offset this alleged increasing charge. Table 3, column G, shows what the interest amounts to, and therefore indicates the measure, on this reasoning, of the alleged increased cost of maintenance.

This varies from nothing up to £4·12 per annum, and the present value of the series is £20·91. As the present value of the 19 payments of £9·58 is £115·77, it is seen that the interest is roughly equal to 18 per cent of the amount required for both return and depreciation. If this were really the measure of the case there would be no lack of evidence of the cost of maintenance increasing with age.

If there are cases of maintenance cost increasing with age, this increasing cost must of course be met, and any such cases will doubtless have well determined cost data, but the provision should be made directly and not indirectly. It would be curious indeed if on all classes of plant the increasing cost of maintenance were just the amount provided by interest at varying rates, compounded over various periods.

Assessment of Profits.

The amount to be charged to depreciation, or as we prefer to put it, to renewals fund and to improvements fund, before assessing the profits of an undertaking, is the total amount indicated by the portion of the annual charges allotted to those costs. The correctness of the annual charges has already been discussed, and when these have been settled, then the charge against the year's income for renewals and improvements must follow in principle that settlement, subject to any alteration of fact which later knowledge may have brought to light. But this does not permit of any change in the method.

If the sinking fund method is correct for the annual charges, it must also be correct for the year's accounts; otherwise, the annual charges are not true, and if they are not true, the primary object of ascertaining the annual charges—to select plant wisely—is vitiated.

The accountant cannot logically at this stage question the correctness of the charge, he may honour the bill or not, may put away more or less than the correct sum as given by the annual charges, but this sum remains the true measure of the year's debit against the undertaking.

The accountant has a duty laid upon him to insist on his share of the responsibility in providing for depreciation, but he must take up the question at the proper place, that is, in consideration of the depreciation component of the annual charges.

In allowing for renewals and improvements when ascertaining the profits of a business, the accountant is likely to be met with the suggestion that if he puts away the depreciation funds on a straight line basis, investing them at interest and crediting the interest actually earned to the revenue, he will be using a method which gives credit for the interest which is in fact earned and will be charging a sum which represents the real cost over the whole period. This is the method shown in Table 3 and Fig. 3, and it is open to the criticisms which, it has already been shown, apply to that method.

In addition, such a practice is objectionable in that the accountant and the engineer are using different methods in dealing with the same subject, and the accountant is always charging a sum known to be incorrect against the year's profits, and his only excuse would be that it is all the same to the funds in the end.

If Depreciation Reserves are Invested in the Business.

Up to the present one assumption has been that the capital account was closed and therefore the reserve funds could only be lent outside. But for many purposes it is more convenient to invest these reserves in the business itself rather than to lend them outside and raise fresh capital for the extension of the business. There is no difference in principle whether the reserve be lent outside or invested in the business; in either case the money must earn interest and the interest must be credited to its real source.

CONCLUSIONS.

[illegible] accountant, and the engineer.

[illegible] charges for plant, determined in advance of construction.

To determine the amount in the annual charges for depreciation it is necessary to estimate the first cost, residual values, and the physical and economic lives of the various classes of plant.

[illegible] account and to estimate the charge for return on capital.

[illegible] credited to its source.

[illegible] funds as follows :—

(*a*) A renewals fund for providing the necessary money at the end of the physical life, that is, the end of the period during which the plant will give its service satisfactorily under all conditions *outside* the owner's control.

(*b*) An improvements fund for providing sufficient additional money to enable the plant to be taken out of commission for reasons *within* the owner's control and while it [illegible]

The calculation of the amounts to be contributed to these two funds must include the interest which should be earned by the money before it is required at the end of the life.

The amount, calculated as above, which should be in the renewals fund gives the correct diminution in value, when considering the value to the owner, of the plant in place and working, at any period in its history.

The amounts, calculated as above, which should annually be put to the two funds, renewals and improvements, determine the correct depreciation charge against the undertaking for the purpose of assessing profits, fixing rates, and, under certain conditions, assessing the value of an undertaking as a going concern.

The sinking fund method fulfils all the requirements.

The straight line method does not.

All estimates, such as first cost, physical and economic lives, and interest earned by funds, will require revision from time to time either as a result of experience or of changes in conditions.

The authors take this opportunity to acknowledge the valuable assistance given by Mr. S. H. Pook in the preparation of the tables.

DISCUSSION BEFORE THE INSTITUTION, 11 JANUARY, 1917.

Sir **ALEXANDER KENNEDY**: I propose to deal with only one or two points in the paper, not because I think that other points are of no importance, but because these special points are of practical importance not only, I expect, to myself, but also to the greater number of those present. The question which the authors have raised as it applies to new works starting to-day, deciding *ab initio* on its plant and on its allowance for depreciation, is one about which I will say nothing—I propose to confine my remarks entirely to undertakings which are already under way and which probably have long ago adopted some method of estimating depreciation. In connection with such undertakings two really very different questions have to be considered. The first relates merely to the kind of provision which a sound financial undertaking ought to make annually in order that, when its plant is worn out, disused, or scrapped, it may be able to renew such plant without raising further capital. The second problem, and the one which is to many of us much the more important, is the determination of the depreciated value of plant which has been used and which has got to be sold or otherwise got rid of. I have in mind, of course, the many private electrical undertakings throughout the country which are working under Provisional Orders or Acts of Parliament, and which must compulsorily be sold at a certain date. What we require to know is what value [illegible]

[illegible] to the first point—annual allowance for depreciation—that is worked out in many different ways, mostly based on the straight line method or something closely related to it. Some undertakings will put by a [illegible] think it better to invest the money in their own business—others prefer to have no depreciation account, but to write down their capital value every year. These methods might be discussed here for hours, and I doubt very much whether at the end one would be able to prove that any one method was distinctly better than all the others, provided always that the amounts and conditions have been so framed that the financial result is what is required. If that result is obtained, I do not suppose that any undertakings whose position is sound will agree to alter the methods on which they are now working, and have probably been working for many years. It would be practically impossible to change under the circumstances, and it really does not matter very much, so long as the result is the right one. But the second question, that of estimating the depreciation on something that is going to be sold later, is another matter altogether. It is one which affects us all, and as to which no very definite conclusions have yet been reached. Personally I believe that there is only one method which is right, and I believe that, substantially, is the method advocated by the authors.

Sir A. Kenned

Many of us have got to sell property which we now possess—that is, if a buyer comes forward at the appointed time. I do not think it can be said that the sellers are willing sellers, and I am not quite certain that the buyers are going to be willing buyers; but anyhow the sellers—that is, ourselves—will certainly wish to get the highest value which it is fair that they should get, and I have not the least doubt that the buyers (quite honestly) will wish to give us the very lowest value that they can persuade any tribunal to allow them to offer us. It is important, therefore, that we should know what we have a right to ask. Hitherto we have only the experience of the sale of tramway undertakings, and in those undertakings the straight line method has been adopted practically universally. It is one of the many objects of this paper to show how very unfairly this method deals with the seller, especially in the case of a forced sale of plant which has worked for a number of years, but is still within its physical life. I cannot suppose that anyone who has considered the matter seriously could ever take the straight line method as anything more than a crude convention. It has, so far as I know, no scientific basis. It enables us to do without a table of logarithms, it even enables us (sometimes) to do without a slide rule, and it enables us, or rather compels us, to leave out of account all financial calculations whatever! But, after all, we are dealing with figures and with money values, and it is no use to have a method which neglects the most essential considerations connected with the very thing that we are dealing with, because they happen to be complicated or difficult to understand. It is said in the paper that the strong point of the straight line method is the catch phrase—"half life, half value." But it does not in the least follow, however, that at half life a thing has half value; it may be only one-quarter value, it may be three-quarters value. I have heard the phrase used over and over again in a parrot-like way, but it is a statement that needs proof, not mere assertion.

I think that in Tables 8 and 9 the authors have put the matter very clearly from the point of view from which I am speaking, that is to say, the point of view of estimating the value of depreciated and used plant at the time of sale. I think they have shown that the sinking fund method is one which is fair to all parties; and if that is so—as I believe—I trust there may be a general consensus of opinion expressed among engineers to that effect, and that the matter may be seriously taken up and dealt with from that point of view, because it is going to affect us very greatly indeed later on. There is only one figure in the tables which I venture to think is a little misleading. Column M of Table 9 is headed: "Average per cent return on capital," and it will be seen that to the fourth owner this represents 84·46 per cent, whereas in the case of Table 8 he only gets 5 per cent. But that is not really a percentage return on capital; it is a kind of comparative figure, because it has taken into account the £4·7 which ought to have been paid but was not—at least, that is how I read it. The point that I am trying to make, however, is not affected by this percentage in any way. It becomes quite clear from the figures in columns B and H. The purchaser at 17 years pays £37·28 on the straight line table, £51·42 on the sinking fund table; the former amount is only 72·6 per cent of the latter. At 25 years the ratio is only 61·4 per cent, or if the scrap value be taken into account only 51 per cent. It is obvious from these figures that if the sinking fund method is the right method of estimating the value of plant after it has been used for a considerable number of years, it is very important that we should get the method clearly defined first in our own minds and afterwards in the minds of those who have to decide what we shall get paid.

In the third paragraph on page 148 there is an answer to an objection which I have very often heard made, namely that the proportion of the annual charge allocated to renewals becomes larger each year. The authors point out that "that increase is exactly counterbalanced by the reduction of the charge in respect of return on capital," so that that is not any serious objection at all.

Sir A. Kennedy.

I will only deal with one other point, which is referred to at the bottom of the first column on page 151. It refers to quite a different matter, and it raises at once the question of what we mean by "life." As the authors say, whatever system of depreciation we use we have got to estimate the life to begin with. The question is: What do we mean by "life"? If we take a new steam turbine, put it in a cupboard and leave it there for 25 years, it has suffered no depreciation at all, at least no depreciation due to any of the usual causes. Therefore clearly the "life" of a thing which is never used at all is unlimited. I mean the life in the sense in which we are using the word—the life which is affected in some way or other, and reduced, by what is commonly called "wear and tear." So that "life" cannot mean merely years. That is the point which I want to make. By simply putting a thing away somewhere or other and never using it, its life becomes unlimited—it goes on for any number of years. When we say that the life of something is 25 years, we must therefore have some kind and amount of actual usage in view during those 25 years. I think it may be said that we have in view something in the nature of a 25 per cent load factor. Therefore in the case of plant which is used, as some plant is being used to-day, on a load factor of 50, 60, or 65 per cent, it is only reasonably fair to say that the life of that plant is less than the life which we should give to the normal plant doing about half as much work in the same time. This point is, of course, quite different from the depreciation question. Its importance arises in connection with the allowances for depreciation in assessment for income tax, especially in undertakings with plant that is being very heavily worked. The point is alluded to by the authors on page 151, where they say that "such things do not wear out by the passage of time, but by the work which is done by them, and it would be wrong to estimate the life of such a thing merely in years irrespective of work." The point is one which some of us in this country must look at very carefully in these days of heavy income tax, for it may make a very considerable difference to our accounts, and I am very glad that the authors have raised it so clearly.

Mr. Highfield.

Mr. J. S. HIGHFIELD: If we bear in mind that in ordinary electric supply undertakings for every £100 of capital the revenue amounts to, say, £12 to £15, and that out of that revenue something like £2 to £3 has to be provided for depreciation, the importance of the subject raised by the authors is manifest. Sir Alexander Kennedy has referred to the advantage of the straight line law from the accountant's point of view. He rather indicated, I think, that the sinking fund method involved the use of a slide rule and a table of logarithms. The accountant usually prefers the straight line method as it simplifies calculation. The important matter is to make sure that, by the time renewal is required, the sum of money set aside will be adequate to meet the cost. I do not, however, propose to discuss the relative advantages of the two methods, because the authors have so ably handled the matter in the paper. The authors suggest that there is generally a difference of opinion between engineers and accountants on this subject of depreciation, and I should like to refer to what I think are the [illegible] thereto. The engineer is generally thinking of the plant and its efficiency, whereas the accountant's [illegible] in the efficiency of each sovereign invested in the business. The plant is only a means to an end, the end being to obtain the maximum yield with security for the money invested in the business. The object of any business is, having provided the consumer with what he wants to consume, to make a sufficient profit and to provide adequate security that that profit shall be continued. The greater the security the smaller the profit. On the other hand, the greater the risk of loss the larger the profit looked for. An investment business offers a comparatively simple problem as compared with a manufacturing or other business involving the use of plant. In an investment business, all that is necessary in making the investment, which may be in an engineering undertaking, is to make sure of the return and preferably of a continuing return. It will be found that every sound investment business applies a sinking fund or a depreciation fund in order that, as its assets become less valuable, the reserve fund or depreciation fund shall be sufficiently large to replace them. That is purely a matter of thinking of the efficiency of the sovereign. Most persons interested in investment business invest their money in other business that frequently involves engineering skill. The reason they provide a reserve is partly because experience shows that the reserve set aside by the business in which they have invested their money is not always adequate; so that we get one depreciation fund created by the engineering business and a second depreciation fund by the investment business. I think the authors have made a most useful sub-division of the amounts put aside out of income to preserve the profits, by dividing them first of all into provision for the diminution of the value of the plant and secondly for the improvement of the plant. The first is a matter which chiefly concerns the engineer. The second one concerns the people responsible for the business management. The first relates mainly to the preservation of the engineering assets—buildings, plant, cables, and so on. The second relates to improvements in the profit-earning capacity of the plant in regard to its efficiency or magnitude, or to the necessity of improving the plant in order to meet direct or indirect competition. I venture to subdivide the two items with the idea of making the argument clearer:—

(1) The minor repairs carried out day by day or month by month.

(2) Extraordinary repairs carried out at longer intervals, such as the renewal of battery plates, boiler tubes and the like.

(3) The repairs, which in this case may be called replacements, which occur at much longer intervals, such as the replacement of boiler drums, tramway poles, and other renewals taking place over periods of 20 years and upwards. It is a comparatively simple matter for an engineer to decide what amounts will be required and at what intervals in order to meet these expenses.

The controversy between the engineer and the accountant arises largely, I think, through making up the [illegible] accounts dealing with these proper plant renewals and the second set of items called by the authors "improvements." These are as follows:— Mr. H

(1) Provision for installing more economical plant to enable a larger profit to be made. In most engineering plants, and particularly in electrical and steam plants, the chances of further improvement are, I think, very large, so that an adequate sum is necessary for this purpose.

(2) The replacement of existing plant by larger plant. Some provision should be made, but the provision is rather of the nature of capital expenditure. It is a complicated matter and leads to great differences of opinion as to how far the expenditure is capital and how far it should be met out of revenue.

Take the case of an old steam engine or old plant in existing buildings. The engineer knows that he can replace that old engine by a more modern one using perhaps only half the amount of steam. That will enable the existing boilers to do double the amount of work and the existing buildings and land to be twice as advantageous. The accountant very often says, "It is all very well to take out this plant which is an asset. If I keep it it is of some value; if I give it away it is not." Consequently, the engineer is forced by the accountant to keep the old plant and is persuaded to put up a larger plant alongside the smaller one, the result being much less satisfactory from every point of view.

(3) Provision for exchanging old for new plant in order to meet competition brought about by rivals employing the latest methods.

The money set aside for this purpose is rather of the nature of an insurance fund. I think that if the true bearing of the authors' suggested subdivision is kept in mind, the ascertainment of the proper sums for depreciation becomes more simple, and I have found that considering matters under the further subdivision set out above clarifies one's ideas. Generally speaking, it is necessary that any business should grow. It is very difficult to maintain a stagnant business in a healthy state, and for this purpose, apart from the amount set aside for renewals and depreciation generally, it is very necessary so to manage the finance that the cash position is healthy, so that at any time additional money can be found to take advantage of every opportunity that occurs. For this reason it is useful to invest a sufficient sum of money outside the business in liquid securities. There is only one other thing that I desire to mention, namely, the purchase of existing undertakings. I have known of several cases—there is the well-known case of the National Telephone Company, and there are others—of the purchase of undertakings, and, so far as I have seen, the purchase and transfer of undertakings from one authority to another usually results in loss to both sides, and to the public. I hope that long before 1931 Sir Alexander Kennedy, instead of having to take thought, as he has told us, of the amounts he can obtain for the electricity supply undertakings in which he is interested, will be able to give his mind to the more cheerful question as to how the business can be carried on. I hope that there will be a change in the law in regard to the purchase of undertakings, so that we shall eld. have to consider how best to enlarge and make them more prosperous, rather than at what price we can sell them.

urne. Mr. J. Swinburne: One of the most important points in the paper is the attack on the straight line law. To get this point apart from the idiosyncrasies of the particular plant in question, let us take the case of A and B with £1,000 each. A puts his into a commercial bank which, for example, pays 5 per cent compound interest yearly. At the end of 10 years he has his £1,000, plus £500 simple interest at 5 per cent, plus £129·89 interest on the interest; total £1,628·89. At the end of 20 years he has his £1,000, plus £1,000 simple interest, plus £653·3 interest on interest; total £2,653·3. B pays £1,000 for 20 years' lease of a building which is kept up by the landlord, and from which he makes profits which give him the same sum, £2,653·3, at the end of 20 years. It must therefore pay him 5 per cent profit, which he reinvests, or puts into the bank, where it makes interest on its own account. It must also pay him enough to refund his £1,000. If it gives 5 per cent extra, this would give him more than £1,000, as he could re-invest or deposit this. It therefore provides 5 per cent interest and 3·024 per cent sinking fund. At the end of 20 years B therefore also has £2,653·3, made up of £604·8 (being 3·024 per cent for 20 years), £395·2 accumulated interest on this, £1,000 by 5 per cent for 20 years, and £653·3 accumulated interest on the last. Suppose A and B change places at the end of 10 years. A has £1,628·89 in his bank. B has £302·4 (3·024 per cent for 10 years); £78·6 accumulated interest on this; £628·89 made up of 5 per cent and interest on it; total £1,009·89 or £621 less than A; and the remainder of his lease. A therefore pays not £500, but £621 for the lease; and B now has £1,628·89 in the bank, which increases to £2,653·3 during the next 10 years. A is in exactly the same position as B was, and has finally £1,628·89. If A paid only £500 according to the straight line law, he would have more than his share at the end of 20 years and B would have less. In the diagram (Fig. A), A starts with £1,000, represented by the line C D. At the end of 10 years he has his £1,000 (E F), his simple interest F G, and his compound interest on that G H. At the end of 20 years he has his capital K L, his interest L M, and his compound interest on that M N; total K N. B starts with a lease value C D. At the end of 10 years he has sinking fund for 10 years E O, compound interest on it O P, 5 per cent for 10 years F G, and compound interest on it G H. He thus has E P and F H in the bank, and P F is the value of the lease, not Q F as the ordinary straight line gives, or O F as a sinking fund-rate straight line would give it.

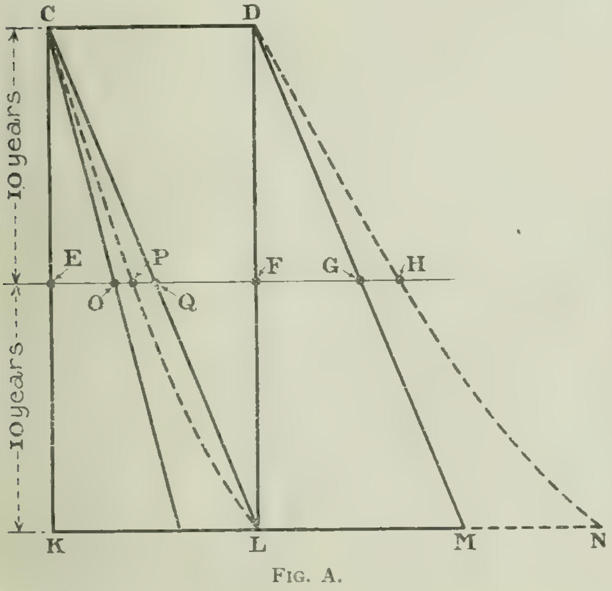


Fig. A.

Mr. Swinburne.

Mr. Kingsbury. Mr. J. E. Kingsbury: I approach this paper as a student, and the impression which I receive is that the element of depreciation has somehow blundered into the scheme of engineering enterprises and that some method of providing for it has gradually been evolved—I will not say by any rule-of-thumb method but in a rough-and-ready way which has no basis of investigation, thought, or science attached to it. That method has been adopted in practice and, like a "custom of the trade," has acquired more or less of a legal status. It appears to me that if the method in ordinary use is inaccurate and unscientific, engineers, who are able to give the subject thought and consideration, ought to discover a better basis. The importance of depreciation has been referred to, and, as the authors have told us, is generally recognized by those who are responsible, but it is apparent that electrical enterprises are to-day suffering from the lack of knowledge of the necessity of depreciation amongst wider areas. The consumer is always ready to say about the capitalists that their capital earns interest while they sleep; but the ordinary member of the public is by no means ready to recognize that the material which the capital buys is dying also whilst they sleep. The result of it is that the lack of knowledge in regard to depreciation has given rise to difficulties which most of us are suffering from to-day in one way or another. A subscriber to a telephone company for instance thinks he is overcharged because some other subscriber to some other company in some other place at some other time was charged upon a basis which omitted the really important element of depreciation. When a paper like this comes before us with a mass of detail, with a logical method of reasoning and with conclusions which, as a student, seem to me to be sound, I think it behoves us to endeavour to reach a conclusion which will show that engineers recognize the necessity of accuracy and method, and that I think will serve in some respects to make more widespread the recognition of depreciation. If one man, for a purpose of his own, or because he gets a little more margin, has a preference for any one method, I feel that he should get the margin, if he wants it, in some other way. The first thing that is essential in every engineering enterprise is accuracy and reliability; but if this important question of depreciation is going to be dealt with not only as a whole but in all its details on matters of opinion, how can we ever expect to reach a proper solution in regard to the relation of values at all? And if there is a method which will put the capitalist and the engineer in a position to estimate with accuracy the value of a plant and the probabilities of its useful life, why should not we use the method?

Mr. Byng. Mr. E. S. Byng: The lives of plant apparently have a most important bearing on depreciation charges and, con-

[illegible] possibly, however, such records are not available in some [illegible] comparatively new. I should therefore like to ask how a [illegible] termed by the authors the renewals and the improvements funds, is most interesting, but it would appear that this

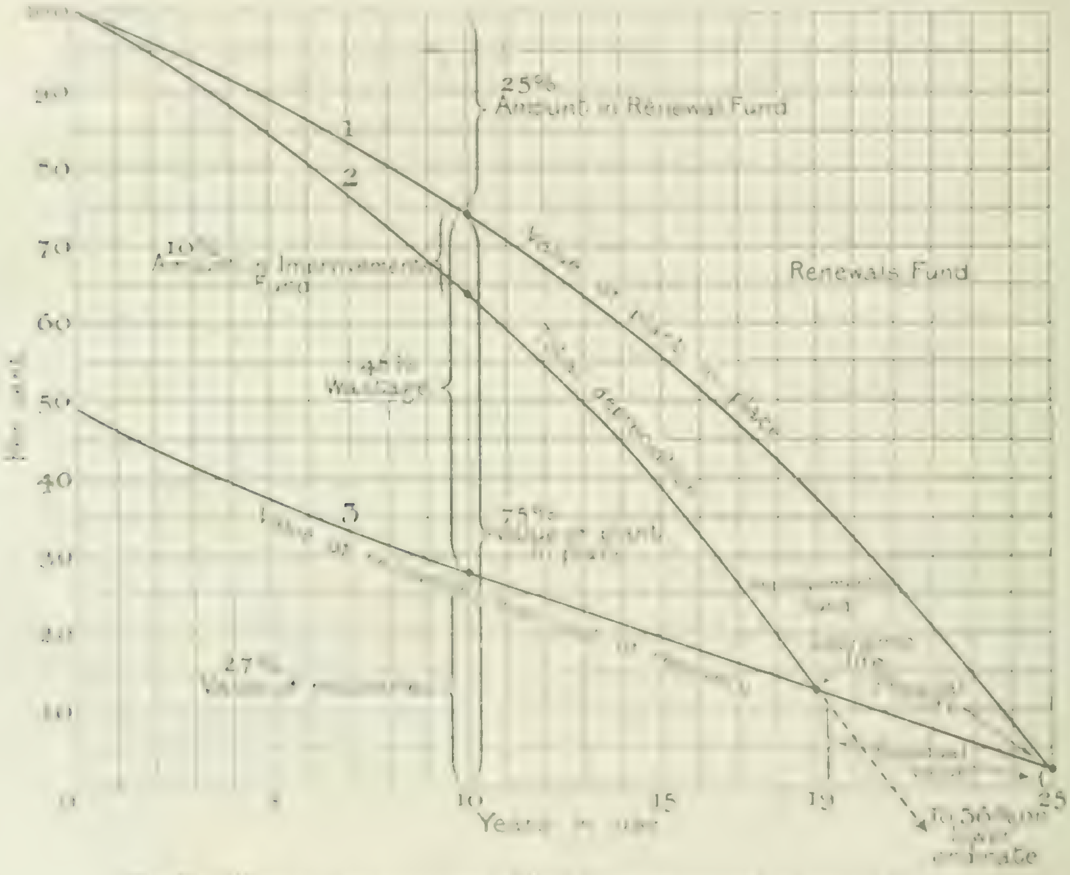


FIG. B.—Wastage [illegible]

will affect the calculation of the "value of plant in place" [illegible] ly when dealing with [illegible] under consider- [illegible] figures given by the [illegible] al life of 25 years and an economic [illegible] invested annually and accumulated [illegible] that the original value of the plant [illegible] necessary marketing have been deducted. If we consider the position prior to the economic life being reached—say at 10 years—and assuming the first cost to be £100, there is an amount of £25 in the renewals fund and the value of the plant in place is £75. If the plant be recovered at this date the value of recoveries would represent £37, thus incurring a net wastage of £48. When considering the advisability of recovering plant at this period it is understood that the amount which has accumulated in the improvements fund, i.e. £10, cannot be taken into consideration although it was for this purpose that the fund was created. The distinction between renewals and improvements gives the value of plant in place a higher figure than heretofore, as only Curve 2 (total depreciation) was previously considered. At the expiration of the [illegible] theoretically there is no loss to the administration if plant be recovered at this date, but so far as the comparative estimates are concerned a wastage of £24 must be taken into consideration. It would seem that the charge for improvements is not continued beyond the economic life of the plant, but it is submitted if it is not necessary to recover the plant for causes within the owner's control [illegible] be continued

Mr. B

yng. throughout. If the plant be recovered at the 25-year period the amount in the renewals fund has matured to its maximum amount of £98 which, after adding £2 for recoveries, was required to make up the total capital, and the amount of £38 in the improvements fund is then an asset not required in this case, but can be used to offset losses incurred through recovering plant prior to the economic period. Presumably, the economic life for any class of plant can be adjusted in course of time as dictated by the financial condition of the improvements fund. In order that those who are not actually engaged in the study of economics, as affecting the design of plant, may realize what part depreciation really does play in determining the "value of plant in place" and the consequent wastage due to recovery before the plant has served the life for which it was designed, the accompanying table illustrates an elementary but typical proposition frequently encountered by telephone engineers. The underlying principles, however, are common to all classes of engineering and will probably give a general idea of the manner in which studies of this description are scientifically tackled before any decision is reached. The question is whether existing plant should be scrapped where this has only been in use for a portion of its normal life in order to meet the anticipated future development. The same figures for obtaining the wastage are used as in Fig. B and show a loss of £288; to this is also added an amount required for the re-arrangement of existing circuits, i.e. transferring from old to new cable, seeing that this is consequent upon the proposed change and is an irrecoverable loss so must be taken into account. The capital costs and annual charges shown are hypothetical, and it should be noted that the latter cannot be added direct to the wastage before the present value of the total costs over some pre-determined period is obtained in order to bring all costs to a common basis. In this case 15 years is taken and a multiplier of 10·38 is therefore used. In the second alternative the annual charges are obtained for the existing pipe and cable which are left intact, and also for the additional plant to be laid; by taking these over the 15-year period it will be seen that there is a net difference in the total or true costs of £609 in favour of the first proposal. This demonstrates the importance of the point made by the authors, viz. that it is frequently far more essential to compare the annual charges over some definite period than even the first costs when it is desired to determine the relative economy of various types of plant. I suggest to the earlier speaker who experienced difficulty in persuading the accountant it was sound engineering to scrap a boiler, which was somewhat antiquated, because it appeared in the books as an asset, that it could have been proved beyond dispute by similar reasoning that a considerable saving would have been effected by introducing the more up-to-date plant. In making comparative studies it is unnecessary to include costs which are common to both proposals, as for example, the existing 3-in. pipe which carries an annual charge of £52 in the case under consideration, seeing the total difference would have been unaltered, and further, by using standard costs which are derived from averages carefully compiled a large amount of detail work can be eliminated from these preliminary calculations. It should be noted that when costs have to be considered over several years a slight error in the annual charge may become a serious item when present values are obtained, on account of a large multiplying factor being used, and it therefore behoves us to see that the annual charges are founded on right lines. As depreciation is a factor which affects these charges to a large extent, it is somewhat surprising that engineers have not been more concerned in the past as to whether correct figures and correct methods have been adopted, and it is in this connection that we are much indebted to the authors for having placed the whole of the facts so logically before us. Mr. Byng.

PROVISION OF ADDITIONAL CIRCUIT CAPACITY IN UNDERGROUND CABLES TO MEET FUTURE DEVELOPMENT REQUIREMENTS.

Existing plant.—One mile 200-pair 10-lb. cable in 3-in. c.i. pipe.
Additional capacity required.—400-pair 10-lb.
Alternatives—
(*a*) Withdraw 200-pair cable and pull in 600-pair cable
(*b*) Lay an additional 3¼-in. pipe and 400-pair cable.

Costs—	£	£	£
(*a*) First cost of 200-pr. 10-lb. cable	600		
Value of cable in place (10 years) at 75 % . =	450		
Value of recoveries less cost of recovery at 27 % =	162		
Wastage due to recovery			288
Re-arrangement of circuits, etc.			110
Annual charges—600-pr. cable, £1,500 at 8 % =	120		
" " 3-in. c.i. pipe, £750 at 7 % . =	52		
		172	
Less " " 200-pr. cable, £600 at 8 % =		48	
Total annual costs . =		£124	
∴ Present value of A.C. for 15 years at 5 % = 124 × 10·38 ... =			1,287
Total cost			£1,685
(*b*) *Existing plant*—A.C. on 200-pr. cable, £600 at 8 % =	48		
A.C. on 3-in. c.i. pipe, £750 at 7 % =	52		
Proposed plant—A.C. on 400-pr. cable, £900 at 8 % =	72		
A.C. on 3¼-in. c.i. pipe, £700 at 7 % =	49		
		£221	
Present value of A.C. for 15 years at 5 % = 221 × 10·38 ... =			£2,294
Conclusions—			
Balance in favour of proposal (*a*)			£609

Mr. Lawrence. Mr. AUBREY T. LAWRENCE: What the layman perhaps does not always realize is that one function of the lawyer—I will not say he always fulfils it—is to have a logical mind. He deals with all sorts of subjects which he knows nothing about, and he endeavours to find out the proper reason for things. When I studied the authors' arguments on the question of depreciation, it seemed to me that there was really only one side that had any logic about it. If we are going to hoard our depreciation fund in a stocking there may be something to be said for the straight line method; but if we adopt the common-sense method and make use of our depreciation fund we get some return for it. That return is not taken into consideration at all, so far as I can see, in the straight line method. I have been waiting to-night to hear some defence of this method on the lines of the argument which I listened to for several days from a most able man, Sir John Simon, but I find that no practical man is prepared to stand up here and defend it, and I am not surprised.

Mr. Cooper. Mr. W. R. COOPER: I hope the income tax authorities will take notice of the authors' remarks and in due course allow depreciation in a way they do not at present, instead of insisting upon our paying taxes on profits which are not earned. There is only one point that I should like to [illegible] that I am afraid some people may be [illegible] after reading the paper to [illegible]. The difficulty is that we are given only two points—the value at the beginning of the plant's life and at the end of its life—and we have to draw a curve between them, and of course there are infinite possibilities under such circumstances. Does the value of the plant follow any one of the possible curves? Probably not. The sinking fund method gives one of these curves. But suppose the compound interest law had not been discovered, the curve would be different; yet the value of the plant would be the same. That brings me to what seems to me to be the real question, namely, what would a fair-minded buyer pay for the plant in question? Is the asset really there? That means, if we are to be in a sound position, that we must have a valuation to check the curve from time to time. One sees the difficulties that municipal authorities get in occasionally through neglecting a precaution of this kind. They find that they require new plant, but do not wish to take out that which is out of date because then there would be no corresponding asset and the Local Government Board would raise difficulties. As Mr. Highfield said, the accountant comes along and [illegible] the engineer. Surely it is time the engineer over[illegible] the accountant, had a valuation, and did things in a proper way. The question is receiving a great deal of attention in the United States from this point of view. The Joint Committee on Valuation of Ohio Public Utilities considered all the systems of depreciation and came to the conclusion that the only sound method was to have a valuation.* Of course, the valuation should be a true one, not merely by some book formula. The advantage of such a method is that it takes account of rapid depreciation, if such occurs, and of obsolescence. Mr. Highfield also referred to the calamity that is expected in 1931. We shall all agree that it will be a great calamity if it does come. Many changes of opinion are taking place at the [illegible] time, the near future will show many things in the [illegible], and surely by means of organization it should be possible for the electrical supply companies to mould public opinion sufficiently to avoid that calamity.

Mr. Scott

Mr. E. Kilburn Scott: About eight years ago I was retained by an Australian municipality in connection with a rating appeal by the local tramway and power company. The municipality assumed the depreciation at certain figures, and on the other hand the company wished to show it was much more, so as to get their rates reduced. [illegible] d extra wear of the rails. [illegible] its in court, such as badly worn rails from the turnouts, also butts of poles eaten by [illegible] of the usual type with purely legal training and [illegible] also that if [illegible] r the other may bring into [illegible] "present values" of plant, it is easy to see how it came to be used. Two parties agree on the initial value of a plant, say £1,000, and that its scrap value after a certain number of years will be, say, £100. They now wish to arrive at a fair value for taking over at an intervening year. The owner will naturally want to sell at a price lying above the straight line joining the initial an scrap values. He argues that the plant has a higher value as a going concern, especially during the earlier years, and that the depreciation is greater towards the end of its useful life. In other words, he wishes to sell on a "value to owner" curve. On the other hand the buyer will doubtless want to purchase at a point on a curve lying below the straight line, and which may be called "value to purchaser" curve. Clearly the best thing to do is to compromise on a price between these two values, and this will be on the straight line joining the initial and scrap values. Regarding what should be done with funds set apart from year to year, some maintain that the money should be put into a bank or trustee stocks at a low rate of interest so that the capital can be immediately realized, whilst others say the money should be invested in the business itself. Generally speaking, accountants insist on the former, but why should engineers and those running electrical engineering undertakings agree to act as if they were executors anxious to escape financial risk, or elderly spinsters who must have the money absolutely safe? It seems to me that it would be an excellent thing if some of the money were placed in sound industrial concerns which are dependent on the electrical undertakings. In a mining area, for example, the electric power company might be financially interested in collieries worked with current supplied by the company, and possibly also from which the company obtained its coal. Again, in Lancashire, municipal electrical committees might place some of the money in the debenture or preference shares of a textile manufacturing company supplied with current from the municipal electricity works. Why should not power companies share in the financial prosperity of the industrial concerns which they enable to carry on successfully by providing cheap power? This is done abroad through the ramifications of the industrial banks system, and it has also the advantage that the suppliers have some sort of control over users of electricity; I see in it a way of helping the establishment of the newer and very profitable chemical industries in which electrical power plays a considerable part. Another point I wish to make is that the cast-iron methods of writing off plant at regular rates from year to year, so beloved of the accountant, retard engineering progress. Who has not seen old generating plant cumbering municipal power houses, which is supposed to be stand-by plant but is there because it stands in the books at a higher value than it will fetch as the scrap which it really is? In Australia I once saw a large number of old locomotives standing in a station yard and found that the reason they were not broken up was because they still stood in the Government railway books at certain values and were waiting until the life assumed had been reached. In the meantime they were occupying space and rails quite uselessly. Accountants only take into consideration depreciation on the plant itself and ignore the cost and trouble involved by uselessly occupying space. The habit of scrapping plant boldly and often wants cultivating in this country, and a step in that direction would be to reduce the figures officially assumed for useful lives of various kinds of plant. If the plant has a longer life, so much the better, but do not put a brake on progress by keeping plant standing idle in order to fit in with cast-iron rules of accountants, councillors, or other non-technical people.

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* [illegible]

Sir C. A. KING (*communicated*): It may be of interest to the members to know that the Post Office in its accounts on commercial lines adheres to the straight line method for two reasons: (*a*) it is the safer course, and (*b*) it is simple.

Sir W. PLENDER (*communicated*): Where all factors which customarily enter into a calculation of depreciation can be determined with reasonable accuracy, the sinking fund or annuity methods advocated by the authors unquestionably present distinctive features of great value for the accurate measurement of depreciation. These conditions obtain in a marked degree in the case of leaseholds, and the practice is almost universal of providing for depreciation of assets of this character by means of a sinking fund or annuity. The practice is, however, different in regard to depreciation of plant, the following methods being most frequently employed: (*a*) By charging against profits a percentage on reducing book values. (*b*) By charging against profits an equal annual sum spread over the estimated life of the asset; this method is known as the straight line method. (*c*) By charging against profits all expenditure on renewals. The last method (*c*) of meeting depreciation by charging all renewals against profits is to a great extent peculiar to large public undertakings such as railways, docks, etc., and presumably was originally adopted on the theory that undertakings of this character have an indefinitely prolonged life and that consequently if wasting assets be renewed from time to time out of revenue, depreciation in the ordinary sense may be ignored. Methods (*a*) and (*b*) above represent commercial practice, the former being more generally used than the latter. Table 1, Column D, of the paper illustrates how method (*a*) operates, and it will be seen that the provision for depreciation in the early years is much more generous than in the later years of the life of the plant. The general adoption of the principle by commercial companies of providing more heavily for depreciation in the early years may perhaps be traced largely to the following considerations:—(1) Uncertainty in regard to the economic life of manufacturing plant; (2) anticipated increase in running and maintenance charges during the later years of life. In effect the attitude taken up by commercial companies as a whole towards the question of depreciation is influenced more by policy than by a scientific assessment of the different elements of risk; the continuity of each company's business is of such vital importance to the shareholders concerned that it has been thought desirable to adopt methods of dealing with depreciation which reduce to a minimum the risk of loss arising from the early obsolescence of plant. It might be said that what is recognized as a proper method of calculating depreciation in the case of leaseholds should, if fundamentally sound, be equally applicable to the case of plant; but it should be remembered that the calculation of depreciation is at the best an estimate into which many varying factors enter, and in the case of a commercial company, liable to close competition, it is not surprising that safety is looked upon as the first consideration, and that this principle has been largely instrumental in determining the commercial practice in relation to depreciation. In this connection it is interesting to compare the elements of certainty and uncertainty which enter into a calculation of depreciation on a sinking fund basis in the case of (*a*) leaseholds, and (*b*) commercial plant:—

Sir W. Plender.

Factors required for Sinking Fund Calculation	(*a*) Leaseholds	(*b*) Commercial Plant
First cost ...	Known	Known
Residual value	,,	Can be estimated
Physical life...	,,	,, ,,
Economic life	,,	Uncertain and difficult to estimate with any degree of accuracy
Interest at which fund should be accumulated	As sinking funds of this character are usually invested separately in high-class securities the rate of interest can be estimated with some degree of accuracy	Uncertain owing to variable net results of working

It will be seen from this illustration that whereas the different elements required for the calculation of depreciation on a sinking fund basis are practically all known in the case of leaseholds, several uncertain factors, subject to wide fluctuation, enter into the calculation in the case of plant. Whilst, therefore, the sinking fund method must be recognized as a scientific process well adapted for assessing the economic shrinkage in value of an asset under certain conditions, its application to the case of commercial plant is open to criticism from the point of view of policy where such plant is being continuously used by the same proprietor in the conduct of his business. Where, however, a determination of the value of plant, otherwise than by a physical valuation, affects interests outside the comity of the individual company, such as in the transfer of an undertaking from one proprietor to another, questions of policy cease to have the same operative force, and the sinking fund method has distinct advantages which it might be desirable to utilize in assessing the amount of "depreciation," or, as I would prefer to call it for this purpose, the "economic shrinkage in value." The following simple example will, I think, illustrate an anomaly which might result, under certain stated conditions, from rigidly applying the straight line method of calculating depreciation to the valuation of assets for the purpose of a purchase and sale:—

Example.—Two men, A and B, have £200 each to invest; A purchases a new taxi-cab for £200; B purchases for £200 two second-hand taxi-cabs costing originally £200 each, half the estimated life having expired, on a valuation based on cost less depreciation calculated on the straight line method. Running and repair costs for each of these cabs are assumed to be identical, as also their gross revenue-producing capacity; the economic life of

[illegible]

	[illegible]	[illegible] cabs
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible] capital invested	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

It is seen, under the conditions assumed, that B who invests his capital in second-hand cabs valued on the basis of cost, less depreciation on the straight line method, is enabled to earn twice the revenue which A does who invests the same amount of capital in a new cab. This anomaly would not arise if the sinking fund method of [illegible] were employed, provided a rate of interest be taken for accumulating the fund equal to the rate of profit which would be derived from an investment in a new cab. It is, of course, true that the conditions assumed in the illustration are hypothetical and might not ordinarily obtain in commercial practice, inasmuch as a second-hand machine with half its life expired might not be expected to be so economical in running and repair costs as a new and up-to-date machine; if this factor had to be taken into account the effect would be to reduce somewhat the difference between the return on capital invested (i.e. 10 per cent and 20 per cent in the above example), but would not affect the principle. In the valuation of an undertaking as between a willing buyer and a willing seller, all questions of policy should properly be eliminated. A purchaser is not entitled to reap the fruits of a system of account-keeping which may have [illegible] the seller (and generally by the com- [illegible] plated. A calculation of deprecia- [illegible] must take into account all the different [illegible] it of the various elements of risk should be made. [illegible] to all cases of this character, but if due [illegible] vier in the later years of the life of [illegible] to be valued, I consider that the sinking [illegible] ably advocated by the authors presents [illegible] other recognized methods. In a valuation as between a willing buyer and a willing seller the problem appears to [illegible]

its economic life. The sinking fund method is well adapted to give effect to this principle.

Mr. H. W. H[illegible] *(communicated)*: It appears to be necessary in the first place to consider exactly what is meant, or should be meant, by the term "depreciation fund." By this I understand a fund of such an amount that if added to the present value of the plant *in situ* and fixed for the business of the undertaking as a going concern, the whole should then represent such a sum as would return to the undertakers the amount they had originally put into the undertaking, in the event of their being taken over by another authority. The only time when the value of any part of a plant should be considered apart from its place in the undertaking, is when that part of the plant has finished its useful life or has to be sold out of commission for some other reason. This depreciation fund has to stand the test from other points of view also. It must represent a sufficient sum of money to replace each piece of plant when its life is finished, and the amount of the depreciation fund must also be such that in the event of the undertaking being taken over at its then value, the amount of the fund will stand the test of arbitration or the law courts. Having regard to all these tests, it would appear that any method of depreciation, whether in the form of equal increment added annually, which is practically what may be called "the straight line method," or of a sinking fund or annunity, is but an approximation about which there is bound to be argument when the time comes. Of these two systems, however, it is difficult to find much to commend the straight line method, and obviously if the straight line method be right, then the method adopted throughout the country for repayment to sinking funds by local authorities must be entirely wrong. Incidentally it would appear, arising out of this, that the time has arrived when the method approved by the Local Government Board for municipal undertakings, and that adopted by electric light companies, whose accounts are audited by the Board of Trade, should be brought into line. It is not worth while discussing this side issue at length here, but careful investigation will show that there is considerable analogy between the sinking fund in the one case and the depreciation account in the other, more especially when plant is sold out of commission before its life is finished. If a really equitable basis is to be found in case of compulsory purchase, it is difficult to see, however, how the procedure of valuation on the spot can be obviated. It may be argued that the result of such a valuation may be an amount smaller than that necessary to stand the tests above referred to. That may be so, but the obvious explanation is that in such cases the users have not treated their plant properly and therefore should suffer the penalty, whatever it may be. I cannot say that I altogether agree with the view that a depreciation fund should also provide for what is called "the improvement fund." Taking the case of an electric light station for instance, the consumer, in the amount he is charged, makes a contribution towards the renewal of the plant when it is worn out, but if he is also to make contributions to the improvement fund, then he is helping to pay for machines to be laid down at a future date and of which future consumers will get the benefit. The test as to whether more efficient machinery should be installed appears to be that the new plant should, out of the economies effected, pay not only the outstanding cock.

charges, becoming due year by year on the machinery that it replaces, but also the apportionment due to the depreciation account arising out of the installation of the improved machinery itself. I am very much afraid that the question as to what should be set aside to the sinking fund, can never become an exact science which will comply with all the tests above referred to, as in the first place the reasonable life of machinery can only be approximated, obsolescence if it is brought in—although I do not agree that that should be the case—is an unknown quantity, while the third unknown quantity, on which the life of the plant to a great extent depends, is in the case of an electric light undertaking the development of the district which it supplies. At the same time I venture to think that it is highly desirable that some common basis of agreement should be arrived at between engineers, accountants and lawyers, as obviously until this is done it becomes impossible to do justice to those whose interests depend on their deliberations, and before long undertakings representing many millions sterling may pass through their hands. If the result is unsatisfactory or in any way unfair the electrical industry generally may possibly suffer a set-back, similar to that experienced by the tramway industries, due to similar reasons, among others.

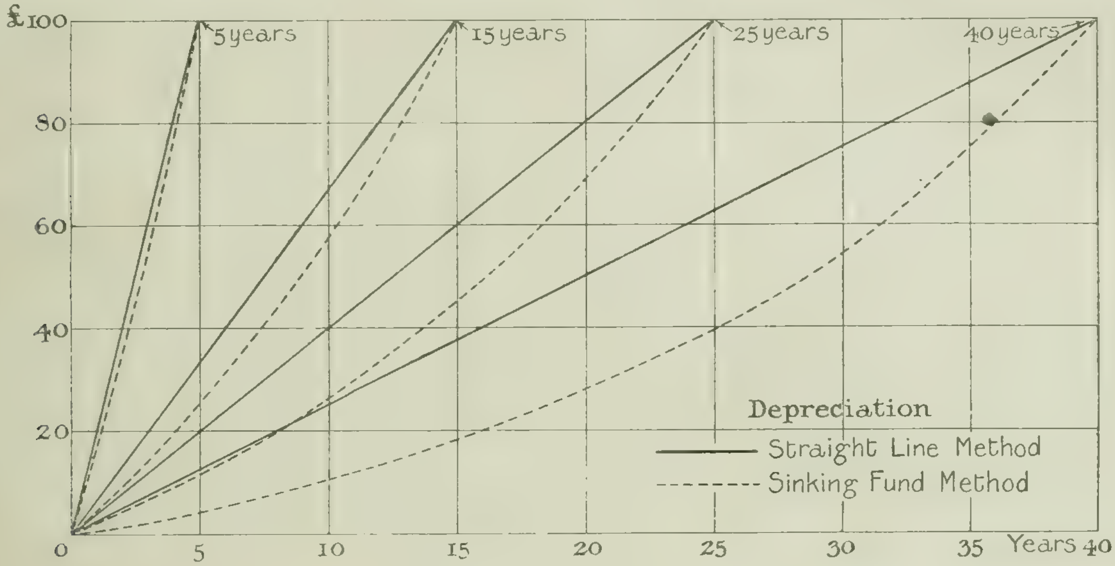

FIG. C.

nan

Mr. Pearman.

Mr. W. A. PEARMAN (*communicated*): This question is of the greatest importance to companies like my own which are liable to purchase in 1931, and I am glad it has been raised. My view of the matter is that after the economic life of the plant has been carefully estimated, a fund should be raised by equal annual instalments, these sums being invested outside the business, and this fund, together with the residual value, should be sufficient to replace the capital expended when the end of the economic life of the plant has been reached. I think the sinking fund method of doing this is the better, as it takes into account all the necessary factors. It does not necessarily follow that a calculation based on any one method for the purpose of ascertaining what profits are available for distribution would be a suitable one to adopt in the event of a purchase as a going concern. I quite recognize that both methods of calculation are supported by expert opinion, and I believe that those who hold with the straight line method do so because in their opinion each year of working reduces the value of the plant by that proportionate part of its life, and the money thus released is a safeguard against unforeseen contingencies. I cannot help thinking, however, that the engineer when he prepares his estimate of the economic life of the plant makes an allowance for unforeseen contingencies. In any case, the same estimate would be used for both methods. I am unable to say what the actual depreciation is, and when it occurs, but I am assured by engineers that the depreciation of the plant due to wear and tear is continuous throughout its economic life—due regard being given to the benefits derived—whilst the possibility of its becoming obsolete increases with its age. It would therefore seem that the sinking fund method meets these requirements, as although a lower sum for depreciation is allowed in each year, the accumulated interest increases each year. The great objection to the straight line method is that it takes no account of the amounts allowed for depreciation earning any interest, and this earning power is a great factor in determining the rate. It must, however, be borne in mind that the regular accumulation of a sinking fund is liable to disturbance from many causes. The rate of interest yielded by the securities in which the sinking fund is invested may, having regard to the price paid for their purchase, differ from the rate assumed as the basis of calculation. Moreover, there will be fluctuations in the value of these securities from year to year after purchase. A general depreciation in the value of securities, whilst it may reduce the total amount of the fund below its proper proportion, may not be an unmixed evil, since it would allow of investments being made at rates more remunerative than that assumed as the basis of the original calculations. A general appreciation of values may also not be an unmixed good for contrary [illegible]. It would be a prudent measure to test the sufficiency of the fund periodically. I have plotted in Fig. C some figures (using 5 per cent interest) showing various [illegible] which one can see the result of both methods in any year. This diagram only gives the amounts that have been provided for the actual depreciation, i.e. the difference between the cost and the residual value. It will be noticed that the longer the life, the more the difference is in certain years. This makes the question of the method to be adopted of very great importance to all electric lighting companies which are liable to purchase. Taking one case, plant with an economic life of 30 years is installed 15 years before the date of purchase: Cost £3,200; residual value £200. The remaining value at the date of purchase under the two methods would be as follows :—

Cost	Written Off	Remaining Value
£3,200	Straight line £1,500	£1,700
£3,200	Sinking fund £975	£2,225

I have given only one instance but a reference to Tables 8 and 9 shows that the buyer gains in every case where the straight line method is used.

Mr. H. F. [illegible] (communicated): I most heartily endorse the opening remarks of the authors to the effect that the subject of depreciation is regarded to a greater degree than is desirable as one for the financier and the accountant rather than for the engineer. But I go still further and say it is one almost entirely for the engineer. An engineer who is not somewhat of a financier and accountant is mostly a mechanic and only somewhat of an engineer. I think it is unfortunate that the authors have not, as a preliminary to their arguments, set forth a list of broad principles to be adopted or discussed with a view to adoption when considering the necessary provision that should be made for depreciation, etc. Before enumerating some of these principles I should like to enter my protest against one or two matters contained in the paper. The authors complain on page 137 (*b*) that the term "depreciation" is loosely employed, and immediately set forth their meaning as covering "renewals" and "im- [illegible]

(1) The term "renewals" may possibly be the correct one, but its use here is unfortunate as it is so commonly applied to the renewals of parts only, as distinct from the replacement of the whole of any particular machine or other asset at the end of life. For example, the Board of Trade Model Form of Accounts for Electricity Works sets forth in the "revenue account for the year" several items of expenditure to be debited as "repairs, maintenance and *renewals*" which are therefore charged to revenue account [illegible].

(2) The subject-matter referred to under (2) in the same [illegible] ally referred to under the term "obsolescence." Now I contend that neither "improvements" nor [illegible]

A few of the matters for consideration and broad principles [illegible] made for depreciation [illegible] remarks referred to as "The [illegible]

A. *The lives of assets under normal conditions.*

(1) Assets, the first cost of which, together with their maintenance in perpetuity, is provided out of revenue (direct), may for the purposes of this subject be considered as having everlasting life; there is therefore no necessity to provide for their replacemement by way of "The Funds."

(2) Assets which depreciate in value unevenly throughout the period of their lives should receive special consideration.

(3) Residual values must have careful consideration having regard to market fluctuations, i.e. market prices at the time of purchase of the asset in relation to those which may be reasonably anticipated at the probable time of disposal.

(4) Where the lives of assets have been equated (see page 149) and (as in the case of municipalities) the accumulated fund may not be touched until the equated period has expired, an additional fund is necessary to provide for the replacement of the shorter lived assets when they are wasted away prior to the expiration of the equated period. This will result in excessive accumulations in the funds which cannot in the case of municipalities be avoided, but regard may be given to such in making future provisions.

(5) Having regard to the remarks in A (4) it is most undesirable to equate the lives of assets unless their estimated lives closely approximate one another.

(6) When an asset is disposed of during its estimated life, the total amount accumulated in "The Funds" in respect of the same should be withdrawn, and the original cost of the asset be written off capital account, the balance required, if any, being taken from the receipts for residuals and if necessary from the revenue account.

(7) New assets taking the place of assets disposed of as under No. 6 or otherwise should be charged to capital direct, and be the subject of the commencement of a new life period.

B. *Accidents.*

The provision of funds to meet special charges which are the result of abnormal accidents is usually the subject of a general or special reserve fund and does not probably come within the scope of the paper.

C. *Obsolescence.*

(8) The estimation of obsolescence periods must be a matter of prophecy.

(9) Every asset should be given a normal life period and an obsolescence period, and "The Funds" should be subscribed to on the basis of the shorter of the two periods, the depreciation fund receiving its full share according to the estimated life of the asset, and the obsolescence fund the balance of the contributions, which will only exist in cases where the obsolescence period is shorter than the life period.

(10) I endorse the authors' insistence "upon the importance of the utmost accuracy in the preparation of the annual charges." Never cheat yourself under the [illegible] supposed to be sound finance to charge capital items to revenue account, but it should be borne in mind that to do so is putting a burden upon either the shareholder or ratepayer on the one hand, or upon the purchaser of the manufactured [illegible] at any

Proctor.

time to be sold, accurate records favouring neither capital account nor revenue account should be forthcoming.

(11) In the case of local authorities working under loan sanctions with statutory repayments, the correct provision in respect of depreciation and obsolescence should be ascertained and compared with the statutory provisions; in the event of the statutory provision being the greater no further provision need be made; if, however, this is not the case then a special reserve fund should be created into which the difference should be paid.

(12) I agree with the opinion of the authors as regards the methods of calculating the funds. The reducing balance method, or written-down basis, must usually cast an undue burden upon the undertaking during its early years of operation and lack accuracy for all time, the straight line method has the same defects to a smaller degree, whilst the sinking fund method allows for a correct provision subject to special treatment for items that depreciate unevenly during the period of their lives.

Rosling.

Mr. P. Rosling (*communicated*): A paper on the subject of depreciation is peculiarly appropriate at this time, when so many owners of plant are considering the question with more care than ever before, and it is much to be regretted that the authors of the paper and the speakers at the discussion, in endeavouring to arrive at a scientific method of apportioning the depreciation per annum, have entirely lost sight of the real meaning of the word. Depreciation, that is loss in value, is, as the authors say, physical and economical, the former is usually brought about by use, and the method of use, and not merely by years of age, and the latter by loss of money-earning power, compared with improved machinery. In pre-War times it was possible in most cases to estimate within a reasonable margin what the physical life would be, and by watching the alteration in circumstances this estimate could be corrected from time to time; busy and slack times alternated, and a plant that was running for, say, 2,000 hours a year at one period easily, might at another be hard pressed for 4,000 hours a year; again, electric plant put down for a lighting load, and a quite easy life, might find itself running 24 hours a day on a power load, with quite a different depreciation factor. To-day, when in many cases plant has been running night and day for over two years, hard pressed, and a minimum of staff to give it attention, the physical depreciation is far in excess of any previous period. As to economical life, even in peace time this was quite impossible to estimate in the majority of cases. Improvements in design, variation in trade, variation in wages, variation in output required, all affected the economic life, and to-day this is accentuated a hundredfold. What is the economic life for machinery put down for munitions? How can this be reduced to a schedule? The authors have further neglected to deal with the question of costs in dealing with depreciation, and this would invalidate any scientific scale that could be devised. To take a case which, though accentuated, is common and typical in degree to others. Electric mains bought in 1913 with copper at say £70, and lead at £13 per ton, and estimated physical and economic life of 20 years, would they have a less value in 1920, with copper and lead at the same price, than identical cables bought in 1916 with copper at £140 and lead at £30 per ton? From the financial point of view, which is after all the view that counts for most, there is only one safe law of depreciation, and that is to write off costs as quickly as possible. Referring to the question of the value of plant for sale, I think very few purchasers would be content to accept as a fair price the original cost, less so much per year of the plant's life, the annual depreciation figure being based on guess-work. They would certainly like to compare the second-hand plant with modern and first-hand plant and first-hand prices.

Mr. Rosling.

Mr. Sayers.

Mr. R. M. Sayers (*communicated*): If it is admitted that the earning power of properly maintained plant remains constant throughout its life—and it is difficult to see any reason to the contrary—there can be no logical objection to its valuation (or the computation of its depreciation) on exactly the same basis as that of a lease or other wasting investment, and the thanks of all engineers are due to the authors for their succinct and clear exposition of the basic principles of the method as applied to simple or complex plant. There is, however, no inherent difference between renewals and maintenance, and any distinction made in practice between the two must necessarily be arbitrary and a matter of convenience. In the case of a structure requiring periodical painting it can be argued that a new coat of paint is a "renewal" of the paint, and, in these circumstances, of course, the life of the paint could be included in the equated life of the plant of which it forms a part, and the cost of periodic painting met from the renewals fund. In a large plant consisting of many units installed at different dates, the annual cost of renewals will, in course of time, become constant—apart from further additions to the plant—and these annual payments could be paid out of revenue as a maintenance charge, provided that the capital representing the plant is not its original cost but a reduced sum taking into account its average unexpired economic or physical life, which (like the annual charge for renewals) will have arrived at a constant figure. The difference between this reduced capital sum and the original cost would of course be the amount of the depreciation computed on an annuity or sinking fund basis. Take, as an instance, the case of a telegraph administration owning a large number of poles, which have been installed at different dates as the plant developed or renewals became necessary. In course of time the ages of the poles will vary uniformly from zero upwards. Let it be assumed, for the sake of simplicity, that each pole is renewed at the end of its 25th year, and that renewals always fall due at the end of the financial year: on a 5 per cent basis the annual payment to the depreciation fund will then be 2·095 per cent of the original cost of each pole. At the commencement of any year 1/25th of all the poles will have a maximum age of 24 years, and the sum in the depreciation fund to the account of these 24-year-old poles will be 93·22 per cent of their original cost. At the other end of the scale there will be 1/25th of all the poles for which, as they have just been renewed, there is no sum in the depreciation fund, a year of their life not yet having expired. It can be shown that the total sum in the depreciation fund will amount to 38·09 per cent of the total original cost of all the existing poles, and a year's interest at 5 per cent on this fund will be 1·905 per cent of the total cost of the poles. As at the end of each year, by hypothesis, 1/25th of the poles require renewal, a sum equivalent to 4 per cent of the total cost must be forthcoming. This is provided by the 2·095 per cent annual [illegible] derived from the year's interest on the depreciation fund. [illegible] the depreciation of the plant as a whole. Having regard to the identity of maintenance and renewals, these figures may be considered as giving support to the authors' contention that maintenance costs are constant.

[illegible] before such bodies as the Institution. The endeavours to arrive at a system which shall be generally applicable have hitherto met with little success, chiefly because the conditions under which they are intended to apply vary so greatly that uniformity is impossible. I think the ques- [illegible] from depreciation. In plain language it means so much per cent profit, and it will simplify the matter if it is [illegible] when permitting an allowance for depreciation, will most certainly not allow interest on capital to be considered. There is no doubt that a fairly accurate rate of depre- [illegible] at in large undertakings, where the conditions of working are the same year in and year out, such as tramways and other public undertakings where precise statistics are [illegible] mills which are designed and fully equipped for one job and never vary in their working. But when we come to general or electrical engineering what a different state of affairs do we find! I am not now alluding to small concerns doing one class of work only, but to the larger [illegible] and it is these surely which are mostly concerned with the proper treatment of depreciation. In such the conditions [illegible] job on the same machine twice in succession; one portion of the works running overtime or double time, other portions perhaps idle or half time. Then the human element must be reckoned with. Manufacturers know to their cost how much damage can and does accrue to costly machines through the carelessness or incapacity of [illegible] To provide against their constant changes, if a percentage [illegible] be adopted, it must necessarily be altered [illegible] frankly state, it is the assumed "life" of a [illegible] forms the basis of any percentage or rate of [illegible] If the estimated duration of life is wrong, [illegible] extent all the rates and calcula- [illegible] gift of prophecy which I venture to suggest no ordinary [illegible] interested. Where our paths diverge, however, is not on [illegible] other words, the "life of a machine." I maintain as the result of a life-long experience in valuing plant and machinery of every description, that the only safe and reasonably accurate manner in which depreciation can be treated is to have periodical examination by a competent person free from bias, who would state the value as the result of his examination. The frequency of such inspections and revaluations is a matter chiefly depending upon the class of machinery and plant. Some are done annually, others triennially, and others again quinquennially, the intervening period being reckoned on a percentage or rate (in a somewhat similar manner to that suggested by the authors) which is corrected and adjusted at each revaluation. This practice is in vogue with numerous important firms, and the number is extending. It will be seen from the foregoing remarks that I am practically in accord with the authors except upon the question of time. In enterprising firms who are continually enlarging and equipping themselves to deal with the changing demands of the times, no fixed rate of depreciation should be permitted for a longer period than 5 years without revaluation to correct and adjust such rate.

The authors emphasize the importance of the subject being treated in a three-fold aspect. In other words they maintain that the desired object to be attained (the accurate treatment of depreciation) can only be arrived at by the engineer, the financier and the accountant. Theoretically this sounds perfect. Let us, however, see how it works practically. To simplify matters we will omit the financier. Now as to the engineer; almost without exception, the larger concerns are limited liability companies, carried on by boards of directors, with managers or heads over the various departments. The chief engineer, who is presumably the one in the mind of the authors, is a very busy man whose entire time is devoted to his work, and who certainly has no spare time at his disposal for inspecting and examining the numerous machines and equipment in a large factory to discover their condition at a given period. But suppose he finds time to do so, has he the requisite knowledge of the value of each machine? I answer, not one in a thousand! His duties are to get the work turned out economically, and he has more than sufficient to employ all his energies in this direction, even if he had the requisite knowledge of values. Would it not be unfair to expect an unbiased opinion from such? I need not elaborate this point further. Now as to the accountant; clearly the authors do not desire to affix the responsibility of determining the rate of depreciation upon him. In this I am entirely at one with them. But, unfortunately, in many cases accountants do not hesitate to fix this rate. Why they assume this responsibility passes my comprehension. I have no doubt that the charm of diagrams and leaning towards tables of statistics has much to do with it. As I mentioned earlier, there are cases where estimates of "life" are fairly accurate, but to apply such tables indiscriminately and to important manufacturing concerns can only lead to trouble, if not disaster.

Mr. F. A. W[illegible] straight line method is unjust and in fact unreasonable. I [illegible] unfairness. At the bottom the service rendered by an elton

efficient machine is a constant annual benefit, and where the life is 20 years the value at the beginning is the present value of the annual benefit treated as an annuity for 20 years. Equally the value after 10 years' working is that of an annuity lasting for 10 years, obviously a greater sum than half the value of the same annuity for 20 years. The only disturbing factor in my opinion is the cost of maintenance, which in many cases is not fixed but very low at first and annually increasing. The accountant can only deal with that factor when the engineer gives him a datum on which to base his valuation. The straight line method, I think, would never have been tolerated but for the fact that lawyers (and also journalists) are seldom very good at figures.

s. Gill ook.

Messrs. F. GILL and W. W. COOK (*in reply*): In the discussion several speakers or writers have dealt with similar points, and in replying it seems best to do so generally under subject heads, rather than to individuals.

The paper is not concerned with what is sometimes termed municipal and company finance, nor with the reserves which local authorities have to make in complying with Acts of Parliament, nor whether the depreciation charge, when ascertained, is paid in the same year, overpaid, or deferred; but it is concerned with the true ascertainment of the correct charge for depreciation of plant whether owned by governments, municipalities, companies, or private individuals. Again, the paper, as stated, deals with the "provision for diminution in value of plant in place and working (that is, its loss in value to the owner as a continuing plant)" and therefore does not refer to the price which can be obtained for second-hand plant, which is usually governed by other conditions.

Some have thought our terminology defective. We defined exactly what we meant by the expressions "renewals and improvements," as we realized the danger of using terms employed in various senses by different writers, for example, obsolescence. The term depreciation was employed as being the generally accepted expression.

In the discussion the treatment of depreciation has generally been restricted to the questions of assessing the profits of an undertaking and to valuation, but depreciation is an important factor on several separate occasions, and it may be worth while to state them here.

(*a*) Before plant of any magnitude is constructed it is necessary to ascertain which of alternative plants is the most economical to employ for the purpose, and among the annual expenses the item for depreciation will play an important part.

(*b*) Either before construction, or soon after, it may be necessary to determine the rates to be charged, and these charges have to include provision for depreciation.

(*c*) After the plant is in operation, costs have to be ascertained and profits determined, and if depreciation is ignored in either of these cases the results are likely to be serious.

(*d*) When it is proposed to scrap any plant in favour of a larger or more efficient type, it is necessary to compute the savings which will be effected and the loss of capital involved. Depreciation enters into both calculations.

(*e*) In the event of a sale of plant on tramway terms, depreciation of the plant has to be ascertained on one basis, and—

(*f*) If the business is sold as a going concern it may be necessary to compute the depreciation on another basis.

Messrs. Gill and Cook.

It will be seen that sometimes the engineer and sometimes the accountant is the more intimately concerned, but in no case can either logically act quite independently of the other, and unless the same method of providing for depreciation be used on all the occasions the accountant and the engineer will be at cross purposes.

The real point to settle is how to ascertain the capital charges, i.e. the expense which the mere ownership of working plant involves, apart from the money actually paid out for its maintenance and operation. Generally the discussion has shown no difference in opinion as to the need for provision for depreciation, and the methods referred to (not necessarily advocated) by the speakers seem to have been—

(1) Charge all renewals against the year's profits.

(2) Be guided by expediency or policy, and write off as quickly as possible.

(3) Follow a definite and detailed fundamental plan providing for depreciation year by year.

Now if it is proposed to charge all renewals against profits as they fall in, and if no depreciation reserve is made, there is no certainty that the undertaking will in fact be able to carry out the renewals when they become necessary, especially in connection with growing plants, and in addition the assets are at all times less than the capital liabilities, unless and until a complete renewal takes place or unless appreciation to the same extent has taken place.

We cannot see how any reliance can be placed on policy or expediency in providing for depreciation except after a calculated assessment. It is quite likely that the politic or expedient method will provide less than what is really required, and in any event such a method (or want of it) provides no ground for better work in the future; each year a leap in the dark is taken, and since there is no measurement, next year's leap is made with no better chance of success than before.

With reference to a fundamental plan of providing for depreciation, the various speakers raised the following points :—

(*a*) The life, particularly the economic life, is uncertain. We admit this; we say that the best judgment and assistance available must be applied to this problem and in the end there will be a much nearer approach to accuracy by making a serious estimate of the life than by saying it can't be done.

(*b*) Life is not measured by time only; plants previously running easily are now running with heavy loads for long hours at an increased rate of depreciation. We dealt with this point in the paper (page 151) and we think that section provides a complete answer to what is an obvious need.

(*c*) Life cannot be arrived at by one estimate to cover the whole time. This is quite true, and we do not suggest it can be. There are several references in the paper to the necessity for constant revision, not only of life but of all data, the last conclusion (page 154) being the summary. In all these estimates the best judgment supplemented by all available data must be used, and this data ought to be constantly growing more and more satisfying, and if these are constantly revised, the estimates and results will become more alike as time goes on. The contributions [illegible] as long as the plant is in [illegible]ent.

[illegible] year it is proposed to extend the hours of working to such an extent that the remaining physical life will be shortened [illegible] of 28), all the other factors remaining as in Table 12. [illegible] when such a course is decided upon the depreciation rates should be revised, and in this case the result would be

	[illegible]	To [illegible]	Total [illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Although the lives in Table 12 are not very appropriate to this example, yet it illustrates that the increased rate of [illegible]on required for shortened lives is easily found and [illegible]owed for.

(*d*) Prudence requires something more in the way of provision for depreciation than that given even by the best estimates. We believe that it is impossible to make any prudent provision without first making the best possible estimate. Assuming this estimate made, the question arises as to whether some extra provision demanded by prudence shall be given, and if so how? The whole paper is an attempt to arrive at a method by which an accurate superstructure shall be built upon the best estimates which can be formed of the primary factors, first cost, lives, residual values, and the value of money. The estimation of some of these factors is difficult enough, but if they are made with all honesty of purpose and with the best knowledge obtainable, and are revised as often as may be desirable, it is difficult to see what greater accuracy one can get; and it is certain that any plan of putting to depreciation sums arrived at without the detail consideration advo[illegible]. [illegible] precautions to make estimates of the primary factors as correct as possible, and thereafter employ a method of calculation which introduces no errors of its own, rather than, because the primary factors are admittedly not ascertained, use with the same factors a [illegible]hod of calculation with known errors, or use no [illegible]ver. Further, if all these primary [illegible] under constant revision, as we advocate in [illegible] there is nothing like the chance of error as [illegible] [illegible]es some additional assurance, it seems to us better that the extra should take the form of a reserve [illegible]

With reference to the method to be followed, no one has [illegible]lf of the reducing balance method. Sir [illegible] states that the straight line method is used by [illegible] to repay terminable [illegible] or other loans which form the capital, the [illegible] Fig. 4 and Table 4. That is to say the depreciation fund is exhausted each year by renewals and paying off capital, consequently, although it does not earn interest, by reducing the capital it saves return on capital. The result is that the Post Office while writing off the capital in the time estimated as being the life of the plant, ignores the progressive saving in the return it has to pay on its capital and no credit is given to the subscriber for this lessening in the capital charges. The engineer gives the effective life at 20 years and (let us say) 13 per cent residual value; the department uses these figures, but by neglecting the, say, 3½ per cent allowed by the Treasury on the depreciation fund balance, makes a financial provision which can only be correct if the life is 17 years. If the department really wants to reduce the engineer's estimate of life by 15 per cent why not do so openly?

The sinking fund method (and by this we mean that the money provided for depreciation is put away at interest, which is added to the fund, in such a manner that the fund including the earned interest can be drawn upon as required) has been further supported by the illustrations given by Sir W. Plender, Mr. Swinburne, Mr. Byng and Mr. R. M. Sayers—all of which are most useful. We have never seen a single case worked out which does not lead to the same conclusion of the correctness and equity of this method. Opponents of it almost always confine themselves to negations stated in more or less general terms, and carefully avoid any quantitative statement whatever.

With regard to valuations, these may be required for the owner, for sale on tramway terms or for the sale of a going concern. In each case the valuation must be as accurate as it can be made, and no valuation on a merely convenient plan will suffice. But the valuer, whoever he may be, must have some method along which he can work, he cannot assess the value from mere inspection, he must have some method of computation. In reply to Sir Alexander Kennedy's question regarding the 84 per cent in Column L of Table 9, our assumption was that the fourth owner receives £8·92, the same as the first owner, and as he has only to pay out £3·92 to the renewals fund, the balance, £5, is his return and is 84 per cent on his capital expenditure of £5·92, Column B.

An illustration of the very real nature of this matter is given by considering the effect of the 14 London electricity supply companies being sold on a straight line valuation instead of on a sinking fund basis. If we assume the cost new to be approximately the capital expenditure, £15,000,000, the physical life 25 years, the interest 5 per cent, and the residual value 2 per cent, probably sufficiently near to the real figures, then the application of these two methods of computing depreciation would result in a difference in the valuation which, varying with the age of the plant, might easily be between £1,500,000 and £2,200,000.

The point has been raised as to whether the fall in value of the plant really follows the sinking fund curve. If one really knew just what happened to the plant, that would probably be an end of the whole matter, but the fact is, as stated in the paper, that the only solid ground is that at any date the plant is so many years nearer to the end of its life. Here the straight line and sinking fund methods are on common ground. In the cases illustrated in Figs. 3 and 6, each makes the charge for each year to the plant, or user of it, an equal portion, the difference being that the straight line method demands 1/19th of £87 = £4·58 each year, while the sinking fund method demands 1/19th of £54 only = £2·85 each year, because it recognizes that this money received in advance of being required will itself earn interest until wanted. The alteration in the slope in the sinking fund curve is not related to the plant; it is of course the accumulation of the reserve, a purely financial operation. The paper shows in Tables 8 and 9 that if applied to the plant the sinking fund method produces fairness between buyer and seller, and we submit that this is a very strong case. It seems to us that the onus of proof regarding the unknown law of plant conditions rather rests upon those who seek by this reference to justify a method demonstrably unfair.

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* [illegible]

The necessity for the two funds, renewals and improvements, is doubted by several speakers. Examining the list of six occasions at the beginning of this reply, it is seen that in cases (*a*), (*b*), (*c*), and (*f*) the total charge for depreciation (renewals plus improvements) is required, and in cases (*d*) and (*e*) the amount in the renewal fund alone is required. By having the two funds any occasion can be properly dealt with. In a scrapping calculation the amount in the renewals fund alone is considered until it has been found economical to scrap the plant, and then the sum in the improvements fund is available to carry out the operation.

The distinction between small renewals and maintenance has also been referred to. While the principle in deciding whether small renewals shall be paid for out of renewals fund or from maintenance is only important in a case of valuation, it is essential that this matter be treated thoroughly in all cases, and that the effect of these small renewals be brought into the calculation of the amount required for depreciation. For example, in the case given in Table 12, if sub-class C be renewed out of maintenance and only the repayment of capital for that sub-class at the end of life of sub-class A be required from the depreciation funds, the annual amount for depreciation (renewals plus improvements) will be reduced by 30 per cent, the equated physical life altered from 43·9 to 56·3 years, and the equated economic life from 28·3 to 34 years. While this method may be quite convenient in dealing with the annual charge for depreciation, the real life of each part must be considered and the matter treated as in Table 12 when a valuation is made.

On the question of constant maintenance cost, as stated in the paper, if there is evidence of increasing cost, provision for this should be made as such and not be confused with depreciation. No speaker has given more than an opinion regarding the alleged increasing cost, and we still feel that, apart from renewals, constant maintenance cost is a tenable assumption.

It has been suggested that the method we advocate involves difficult calculation and book-keeping. Any logical method of calculation involves the same factors of first cost, lives, and residual values; the sole additional factor being the interest on the depreciation funds. By using well-known tables the calculations are as easy in one case as in the other, and there is not much difference in the work involved in calculating 87 ÷ 19 = 4·5789 (Table 3) and 87 × 0·032745 = 2·8418 (Table 6). No description of the accounting forms by which the principles advocated are carried out was included, but they exist and are in operation; no difficulty and no uneconomic amount of work prevents their adoption, and it is quite feasible to keep in touch with the whole subject and revise all the data as and when required.

Messrs. Gill and Cook.

Several speakers have raised questions relating to the position of the engineer with regard to finance. The engineer of any concern where plant is important, if he is to do his duty, must be largely concerned with finance. It is he who really determines what plant shall be constructed, and when that selection is made it follows that of the annual expenditure there is determined all the return on capital, all the depreciation, and a very considerable part of the cost of operation and maintenance. In fact before the plant is constructed the bulk of the annual expenditure is settled, and the management has only a margin on which to do better or worse. In normal cases, if such a concern is not commercially successful the engineer must take a large share of the responsibility, if he has been given his proper place in the organization.

The curve of value of plant in place, the method of deciding when to scrap plant, and the standard costs, all referred to by Mr. Byng, are good examples of methods used to enable engineers to carry out this part of their work properly.

Mr. Handcock's communication has been received as this reply goes to print; he suggests that it is incorrect to provide for improvements in advance, and that they should be defrayed out of the economies to be effected. This important matter has also been raised in the discussions at the Local Sections, and as full reports of these are not yet available, we will reserve our arguments in favour of the course we advocate until replying to these discussions.

The discussion has been very encouraging from the point of view of getting a consensus of opinion upon the proper treatment of this subject. We hope that the matter will not be allowed to drop and that those to whom the subject appeals will endeavour to follow up the idea suggested by Sir Alexander Kennedy, Mr. Kingsbury, and others. Among other things which ought to flow from a general consensus of opinion is a more logical treatment of loan periods by the Local Government Board (assuming that the loan periods really have relation to the life of plant) and of the deduction for depreciation allowed by the income tax authorities. At present these are difficult to reconcile with facts and with each other.

SCOTTISH LOCAL SECTION, 9 JANUARY, 1917.

Mr. F. A. Newington: On the first page of the paper, I wish to differ from the authors in their definition of renewals, as they class ordinary wear and tear as renewals. It seems to me there is a large difference between replacing small parts of machinery and entirely renewing. To talk about renewals which are really ordinary items of maintenance is, I think, not right. I do not think that renewals is a good term; it should certainly be reserved for the larger parts only. Later on, the authors refer to poles, but when a pole is done at the bottom it must be

Mr. Newington.

[illegible] and here the term renewal is quite [illegible], but with respect to [illegible] machinery we can [illegible] parts in [illegible] and I do not look upon that as a renewal. I have not had occasion to consider the straight line method referred to. Municipal [illegible]gs have to borrow money and pay off their [illegible] according to the Electric Lighting Acts, and [illegible] Our revenue has to be used for certain specific purposes : that is, (1) in payment of working costs, maintenance and outlays of that sort ; (2) in paying interest or dividends on mortgages or borrowed capital ; (3) in providing a sinking fund for repayment of borrowed money ; (4) in payment of any special expenses ; and (5) in providing a reserve fund if they think fit. The reserve fund, however, is not to exceed one-tenth of the aggregate capital expenditure. In this there is nothing about renewal or depreciation funds, and it seems to me that according to the Act it is illegal to provide either depreciation or renewal funds. We are allowed to provide [illegible] and we pay off our debt by means of the sinking fund in a certain term of years which, as a rule, may vary from 25 to 30. This is somewhat similar to Table 6 except that, under the usual method of paying off by fixed sums each year, the interest yearly decreases because the amount of capital is reduced. In Table 5 the point seems to be that depreciation increases year by year or that depreciation plus interest remains the same. Our method of paying off capital is by making equal annual payments over the period, and I think this is the universal method for electricity supply undertakings who are paying off any fixed sum in any given number of years, the interest payable each year being reduced because of the reduction of the capital originally borrowed. For electricity supply undertakings an average period of from 25 to 30 years for repayment of capital seems quite safe as far as the life of the life of the plant is concerned, as a considerable proportion, such as land, buildings, cableways, etc., will have a very much longer life. It hardly seems possible to say what allowance should be made for "improvements," as this depends upon local conditions. The reserve fund can be used for improvements. Perhaps the authors will consider a scheme by which, instead of payments decreasing annually, as many of the tables show, the payments would be less in the early days of the undertaking when it is not earning full revenue, and later the payments could be increased when the plant was in full operation. If some scheme of that sort could be worked out it would prove of benefit to many undertakings in the earlier stages. I cannot agree with the authors that the maintenance does not increase with the age of the plant. It seems to me that with increasing age the maintenance [illegible]

Mr. [illegible]: As [illegible] of the [illegible] Committee of Greenock it has been of great interest to me to [illegible]. Our [illegible] has [illegible] been unable to attend this meeting, but he has given me [illegible]. He is [illegible] of opinion that the only form of depreciation which should [illegible] should be that described by the authors as the straight line method ; [illegible] what I have gathered as a member of the Greenock Electricity Committee for the last 15 or 16 years, I do not think that the straight line method is the right one. Our Chamberlain said he thought we ought to have a stated number of years in which to pay for buildings, ground, and machinery. I do not consider that to be the correct policy, and I think that the Secretary for Scotland should allow electrical undertakings at least 60 years to repay the money borrowed for land and buildings. In addition to our reserve fund, which we are allowed to increase until it equals 10 per cent of the capital expenditure, I consider it necessary also to provide a renewals suspense fund such as has been established in Manchester. Take the case of a valuable piece of machinery which through unforeseen circumstances breaks down and requires very expensive renewals or repairs. These circumstances are not provided for in the ordinary estimate of the life of the plant nor in the running costs, and, without some provision such as I have just mentioned, a repair of this kind may be a heavy burden on the revenue account. I have been speaking almost entirely from the municipal point of view. The problem for a company undertaking is, I can conceive, very different, and my general impression is that in the majority of cases sufficient provision has not been made for depreciation.

Mr. R. ROBERTSON: A paper of this kind can hardly be expected to refer to or deal with municipal undertakings because, as Mr. Newington pointed out, the sinking fund is prescribed according to a specified method, that is to say, upon the capital being repaid in a certain number of years, so that municipal undertakings are in a different category from other industrial undertakings. The authors have emphasized the fact that the paper only deals with principles. It is hardly possible, in a case like this, to deal with the question of principles without considering their application in practice, and any remarks that I have to make are really remarks from the point of view of one who has endeavoured for a considerable time to apply principles of this sort in actual practice. Turning to the details of the paper, the first point that occurs to me, looking at it from that point of view, is the necessity or the advantage of sub-dividing this provision into two funds—one for renewals under the heading of "physical life," and the other for improvements under the heading of "economic life." One or other of the two must predominate and, if the one which predominates is provided for, it is unnecessary to take the other into consideration. This, I think, is more evident from the fact emphasized by the authors that the provisions for physical or economic life have to be predetermined to enable allowance to be made. The next point upon which I should like to make a remark is referred to by the authors on page 146. They state there that in practice it is not usual to repay capital fractionally each year. I should like [illegible]. I do not [illegible] any business apart from municipal undertakings—where the capital is repaid fractionally year by year, and I think any method which involves such a repayment is not a method requiring practical consideration. For that reason, the methods described in Tables 1, 4, and 5, while very suitable for comparison with the others, are really of very little practical value. The next point, looking at it from a practical view, [illegible] the question of [illegible] value. These are very tson. difficult to anticipate because, say, in the case of the residual value of a particular item of plant which is expected to be discarded 19 or 20 years hence, it is almost impossible to estimate what that value will be at that distant date. It will depend entirely upon what demand there may be for more or less out-of-date plant, and I think that in practice the introduction of the question of the residual value is of very slight importance in fixing an amount for depreciation. Turning to Table 6, it will be evident that the fact of leaving out the residual value of 13 per cent only makes a difference of another two years in the economic life. It is hardly practicable in the early stages of the use of plant to fix the life at such an exact term that the difference between 19 and 21 years will be of serious importance and, as the authors point out, as the use of the plant goes on the rate may have to be varied from time to time as experience is gained with the running of the plant. In the cases where the allowances are based upon the physical life it is not so difficult to estimate residual values as they really become scrap values, less the cost of dismantling. It appears only to be necessary to introduce the question of return on capital for the purpose of comparisons between the different tables—some of which deal with diminishing return on capital, owing to the fact that it is repaid year by year. This question of the return on capital does not really have any bearing on the question of depreciation. In ordinary commercial undertakings, the question of return of capital is a question entirely apart from depreciation.

The authors point out, very properly, that no particular plant is of such a simple nature that it can be dealt with by one common life or rate of depreciation, which everyone will agree with. But I am unable to see any practical advantage in arriving at an equated life. In ordinary practice, if the capital expenditure is divided up into a number of classes, the plant in each class having a more or less similar life, then the rate for depreciation can be fixed for each class and the totals for the different classes added together in order to get the total depreciation for the year. This method also makes it possible to ascertain at any time the amount of the depreciation fund, including interest, relating to any particular item of plant, depending upon the time the plant has been in use. This can be ascertained either by a series of tables or by curves similar to that shown in Fig. 6, the heavy line showing the total fund. The difference between the amount so determined and the original cost would give the then value of that item in the books. The conclusions arrived at by the authors I agree with generally, with this proviso, that as regards No. 1, it is not always practicable to regulate the various items in advance, particularly in progressive businesses which, in the early stages, cannot be expected to meet all the charges. The remarks that I have already made also indicate that I disagree with the necessity in most cases of dividing up the charges under the two heads of physical and economic lives.

unro. Mr. J. M. M. Munro: In some ways this paper might usefully have received preliminary discussion by the Society of Accountants or Faculty of Actuaries, being thereafter presented to the Institution. Its whole subject, however, is not only most important to engineers, but is based on facts and figures which engineers must provide. Therefore any discussion here of these facts and figures of duration is not out of place, though the argument of the paper is strictly confined to a problem of accounting. The physical life, and still more conspicuously the economic life, of the various types of engineering plant is a problem which we have to face anew every time we are called upon to fix periods for these. With the exception of some tables of telegraph and telephone plant, we have no adequate and convenient authoritative data to go upon. Figures given by manufacturers are not always on a sufficiently wide, disinterested, and prolonged basis. Is there not room for a standing Institution Committee entrusted with the duty of collating reliable records of plant life? Yet even the result of such records, continued over a long period of time, would not yield cut and dried figures. Changes in material, design and principle, not to speak of varying standards of workmanship, constantly occur. So much also depends on position and duty of plant and the care taken of it and the chapter of accidents, that standard periods of physical life are not easily determined. Every engineer has his own way of attacking such problems. The figure arrived at on a widely extended average may be fairly accurate, but on any individual item or set of items it may be far wrong. Knowing the fluctuating value of one's figures, one begins to feel alarmed when skilled accountants build their extremely accurate and deftly balanced structures upon them. Yet it is consoling to know that once the engineer's figures pass from his hands they are subject to methods of carefully considered arithmetical accuracy, and are not therefore likely to lead further astray those who venture their money upon them. Before hearing all the paper, I felt inclined to say that, if depreciation tables were to be based on times and values of probable antiquation, or "improvements" as the authors prefer to call it, then it was unnecessary to consider the longer "physical life" period. I now agree that it is well to keep separate amounts for "economic life," for the reason that the termination of physical life happeneth to all, but economic life is a more uncertain contingency. Sums set aside for the latter are more of the nature of a private insurance fund. It may not be needed, yet what little there is of it is a help if a change in, say, five years be imperative. In a lesser degree the same remark applies to the renewal fund also. Those responsible for plant find it difficult, sometimes, to determine where maintenance ends and renewal begins. The renewal of parts of cables at faults for example, as referred to at the top of page 153, will not usually amount in the end to the renewal of the whole cable. If it did, the renewal rate would be inadequate to cover its share of cost. But, more probably, the cable would be less valuable after all the partial renewals, because of the number of joints made. I take it, however, that patches would be maintenance and only an important new length or part would come out of the renewal fund. The same value of plant varies yearly with market prices of similar plant. There is also the well-known fact that a life estimated at say 30 years is worth say 5 years at the end of 29 years if it then continue in fair condition. But, after all, the figures referred to in the paper ultimately refer merely to the correct method of gradually extinguishing the prime capital outlay. Many of the smaller electric supply undertakings have not, in their earlier years, any cash surplus to furnish an improvement or renewal fund. The authors appear to have made good their argument in favour of the methods of accounting recommended by them.

Mr. Whysall.

Mr. F. H. Whysall: Mr. Newington referred to the methods proposed by the authors for dealing with depre- [illegible] put forward some scheme which would make things easier at the beginning of the loan period in preference to the method shown in Table 4 [illegible] at the beginning than at the end. The Electric Lighting Acts provide for that in one way; that is, they do not demand the first instalment of repayment until the financial year following the year during which the money was spent. In Greenock, we follow out slavishly the lines laid down in the Electric Lighting Acts and make our repayments on the straight line method. I thoroughly agree with the authors in their [illegible] and, if my memory serves me, in Manchester the electricity accountant uses a system similar to that which the authors advocate in the paper; that is to say, as far as accountancy is concerned, interest and sinking fund would be calculated on the sinking fund method shown in Table 6. In this connection I should like the authors to clear up a point that puzzles me. In order that my question shall be perfectly plain, I would state first of all the conditions under which money is borrowed. The loan period is fixed on what is estimated to be the physical life of the plant required, and it is assumed that when the physical life of the plant comes to an end, all capital charges will be paid off and there will be nothing left of either plant or borrowed capital, the Corporation being under the necessity of renewing it by fresh borrowing. We will assume that the physical life decided upon was 30 years and the Scottish Office sanctioned the loan period to correspond. The Corporation then proceeds to borrow money from the public for repayment at the end of short periods—say, 3 or 5 years. The question is, how would the authors deal with their accounts in order to obtain the advantages on capital account shown by their system, Table 6, and meet the conditions imposed for actual repayment by the short loan periods arranged in respect of the money borrowed from the public? The question of plant depreciation is one of increasing importance, and all of us are acquainted with engineers who are suffering much tribulation through the neglect of serious consideration in this connection during the years that have passed. When undertakings are first launched, it is readily understood that there should be a tendency to obtain long loan periods and turn a blind eye to this subject in order to [illegible] it appears to be a profit-earning stage as soon as [illegible]. It is very difficult to persuade municipal [illegible] shareholders of companies that it is to the [illegible] advantage of the undertaking that it should be run at an apparent financial loss during certain stages of its development. I refer to the periods when extensions are under consideration. Some American concerns have been bold enough to install plant, the capital charges on [illegible] this policy of [illegible] to adopt, either the engineer [illegible] large in proportion to [illegible] expired. There is no doubt in my mind that, generally speaking, a sufficient provision is not made for depreciation and undertakings continue to suffer the encumbrance of inefficient obsolete plant which they cannot afford to scrap. South of the border the Local Government Board is becoming very much alive to this condition of affairs with regard to municipal undertakings. The Scottish Office, so far, has not been quite so strict, but there also the tendency is the same (I refer to the cutting down of loan periods). In some cases conditions have been granted which are too short for the plant under consideration. A glaring example is the usual loan period of 7 years for the purchase of a storage battery; this in spite of the fact that most batteries are now installed under maintenance conditions which preserve them in a state of 100 per cent efficiency and keep them in practically a new condition. I am strongly of the opinion that where a maintenance contract is made with the battery manufacturers, the authorities should allow at least as long a loan period as that allowed for generating plant. Believing in the advantages of the use of batteries in connection with electric supply undertakings as I do, I would even go further than this and say that in the case of batteries it would be quite a legitimate case for the consideration of a Government subsidy in these days when war economy is so much to the fore; they might even make it compulsory, on these grounds, that undertakings should provide battery capacity for dealing with all duty of less than 8 per cent daily load factor—i.e. of less than two hours' demand during the 24 hours of the day. Where the loan periods are properly estimated, there is of course no necessity for further provision in the way of depreciation, except in the shape of what, I think, Mr. Pearce has instituted in Manchester and called a renewals suspense fund, which is a special reserve fund from which accumulated moneys can be taken to defray the cost of abnormal repairs or renewals. It is obviously unfair that one year's running costs should be saddled with abnormal expenses connected with serious breakdowns resulting from causes which could not be foreseen and which might legitimately be put under the same clause as that of bills of lading, defining the circumstances under which carriers would not be responsible for loss or damage—in short, some form of insurance in addition to the proper provision for depreciation. In connection with company undertakings, depreciation is a simple matter and the responsibility of deciding on what is necessary rests entirely on the directors, and the provision necessary of course varies with every different set of conditions.

Mr Lack

Mr. W. W. Lackie (*communicated*): In discussing this matter before a sister association I stated that the question of depreciation and its relation to sinking fund is one that still remains undecided. I then quoted from a correspondent to *The* [illegible]: What is depreciation? Is it depreciation of value by reason of wear and tear as described in the Customs and Inland Revenue Act, [illegible] (2) [illegible] a generating station or any portion of its plant no longer able to turn out the quantity of electricity it did when originally installed? (3) Or is it merely obsolescence in the case of plant which is as good for all generating purposes as when it was put down but is no longer up-to-date, something more efficient having been placed on the market? Depreciation of value is met by a sum set aside for a sinking fund, if such sum be properly calculated at the probable life of the plant. This is what the authors call physical life. Decreased efficiency should be met by depreciation if the ordinary maintenance chargeable to revenue is not sufficient to keep the plant in its first state of efficiency. Obsolescence does not mean nor does it involve depreciation. It is not true depreciation; but it is quite possible that a prudent authority owning works might look to the advantage which would be gained by installing present-day plant and so getting greater efficiency than could be obtained from antiquated plant. Such an authority would annually set aside a sum for this purpose and might dispense with old plant in favour of more up-to-date plant even although the former might not have reached the end of its useful life. It is not legal to create a deficit by setting aside a sum either in the name of depreciation or as a reserve fund. Only such sums as are profit are available for this purpose. The Court of Session in 1880 held that the deduction for wear and tear to be made under this section of the above-mentioned Act is a deduction for diminished value as a means of earning income and not as an available subject, and that in as much as the plant in question was undiminished in value for the purpose of earning income, no deduction from income-tax charge could be made beyond repairs already allowed for. I consider there is really no principle involved in computing the depreciation of plant. The examples worked out in the paper are based on a 19 years' life. Let me mention what has happened in the principal power station in Glasgow recently. Ten years ago a 1,500-kw. generator and condensing plant were bought for £16,000. Depreciation has been written off this plant and it now stands in our books at £7,000, i.e. we have written off £9,000 in 10 years. It is proposed to scrap this plant and put down in its place a 6,000-kw. turbo-alternator costing £28,000. The new plant will save us £20,000 per annum in coal and the plant will pay for itself in 18 months, or the proportion of the 6,000-kw. set that the 1,500-kw. set represents will be paid in a year. So long as the plant is kept in first-rate condition out of revenue, and one is prepared to write off the difference between what the plant stands at in the books and what it would fetch if sold, the rate of depreciation might be so small as to be met by sinking fund. No fixed rate of depreciation should be agreed upon over a period of 20 years in an engineering works. One might have a very slack year when the plant was only used for, say, the equivalent of 2,000 hours per annum, and in a subsequent year the same plant might be run for 6,000 hours. The rate of depreciation in the two years would be quite different. In the early days of electricity supply for lighting purposes we thought that a depreciation of 5 per cent was liberal, but to-day with new plant which is run practically continuously a depreciation of 10 per cent is required.

Mr. R. B. MACCALL (*communicated*): It would appear that several factors which do not affect the question of depreciation have been taken into consideration by the authors. I am afraid that I am amongst the Philistines in regard to the conclusions of the authors, first, because I do not think a general agreement is possible, and secondly, because I believe the straight line method is not so inequitable as stated in the paper. Depreciation is like incidence of taxation, a subject on which many divergent views are possible. While all agree that both depreciation and taxation are inevitable there is no common agreement in regard to principles. It is not correct to say that it is largely a question of fact. While depreciation of plant is a fact, the possible period of years in which total loss would occur is unknown, and therein lies the first difficulty in coming to a common agreement. From the financial point of view, depreciation is a setting aside annually (or otherwise) a sum towards the day when the plant will be done and new plant will have to be provided. It is, in fact, a premium of insurance. All life and all business is a betting or bid against futurity, and all that prudent people (including the engineer, the accountant, and the financier) can do is to make reasonable provision for the inevitable but undateable casualty. The question of depreciation has been debated time and again, particularly in the accountant magazines, and an attempt has been made to enforce a fixed depreciation, particularly for municipal electric supply undertakings, but the consensus of opinion was that there was no absolute line to be drawn as regards depreciation and that it must be left to the respective authorities to make such provision for replacing capital assets as might seem reasonable. In this connection I might point out two extremes. A steam engine has been operating in the neighbourhood of Glasgow for over 80 years, yet I have no doubt when the plant was installed its physical life was not estimated to be quite so long. On the other hand, a company was formed to exploit a patent sodium process of producing aluminium and it might reasonably be inferred that the life of the patent was the 14 years for which it was granted and that the company would be successful, as the cost of producing aluminium was a few shillings per lb. when aluminium was selling at about 20s. per lb. Before the company had time to get into practical operation the electrolytic method of production came forward and produced aluminium for pence per lb. so that the patent was practically of no value. In both of the cases mentioned it is quite apparent that no scale of depreciation formed on any physical or economic life would have been anything like accurate.

The factors which the authors have, I think, wrongly obtruded into the question are: (1) annual return on the plant, and (2) maintenance. Neither of these factors has to do with the question, it being understood that the maintenance is always sufficient to keep the plant in good going order, and that the plant is not deliberately allowed to go to wreck. That being so, the true question is: (1) what sum should be put aside so that when the life of the plant, either physical or economic, is finished, there is enough cash provided to replace the unit of plant; (2) should such sum be provided annually, and, if so, should such annual instalments be equal or otherwise? The authors have dealt with only two aspects of depreciation, viz. (1) physical life, commonly called wear and tear, and (2) economic life, commonly called obsolesence; but there is a depreciation due to decreased efficiency, as when a boiler can no longer be used at the original pressure, and depreciation in the income tax sense, where so long as plant can earn its first income undiminished without serious repairs, no allowance for depreciation is given.

To examine the figures in the paper, the first thing that calls for attention is the different rate of depreciation

Mr. Macca

[illegible] alternative A and alternative B. Why should one be at the rate of 6 per cent and the other at 3 per cent? It cannot seriously be argued that a higher priced plant will last longer than a lower priced one, indeed it may possibly be that the lower priced one is [illegible]lly and will last longer. What a higher [illegible] greater efficiency, [illegible] add to the life. If the rate of depreciation be equal in both cases, the total in alternative [illegible] the figures falls. Turning to page 139, I have already stated that the annual return to the investor or owner does not affect the annual rate at which depreciation should be provided; but even allowing that it does, the authors are quite wrong in assuming, as shown in Table 1, that a [illegible] annual return is all that is wanted. In this [illegible]n one has to be careful to distinguish capital [illegible] apart from any bookkeeping or accountant methods of stating accounts. The authors are in error in stating on page 139 that depreciation will vary accordingly as plant is written down by the annual amount of depreciation or as it is put into a fund. The facts must be kept clear. If £5 be written off an asset, that does not necessarily [illegible]vested, but in a municipal undertaking [illegible]ation would be either (1) to repay the [illegible] for it. The financial effect to the undertaking is the same, that is, the net interest payable is now only on £95, i.e. on [illegible] of actuarial calculation. The fact is, taking the authors' [illegible]y owner, individual or body corporate, would [illegible]t for interest and 4·58 per cent for depreciation—[illegible] the investment would be a decaying one. It follows, therefore, that if 5 per cent per annum is required for interest the figure in column B, page 141, also Table 4, should be £95, which with depreciation in column D, £87, equals £182 and is the same amount as shown in Table 2.

With reference to the statement on pages 148 and 149 as to "Alleged Objection to the Sinking Fund," the [illegible] If the plant is to be sold to successive owners [illegible]preciation basis, the net result that the successive owners could look for is to get back their capital invested at the end of the life of the plant, and the statement on page 149 as to plant being sold for 1d. is perfectly absurd [illegible]t it for 1d. all that he could look [illegible] money, that is, he wants his 1d. plus 5 per cent interest for the year, and the advocates of the straight line method would not advocate that he should look for £100. Time does not permit me to go further into this point and I will now turn to the equation of depreciation. For different classes of plant there would be little difficulty in arranging this equation were there only one of each class of plant A, B, and C. The difficulty, although a small one, arises when the amounts under A, B, and C vary greatly; but even then there is no real difficulty, all that requires to be done is to get the amount expended on the different classes and the probable length of life and equate it. With reference to depreciation, in view of the economic life I do not believe in a separate improvements fund. It is quite clear that if the life of a unit of plant can be calculated on two different bases, the shorter period ought to be the one upon which the rate of depreciation is fixed, and it is impossible to make an equation for a physical or economic life on any one unit, although it is quite possible to make an equation sufficient to meet the case where one portion of the plant has only the "physical life" problem and the other portion has the "economic life." With reference to the paragraph on page 153 in regard to "depreciation reserves invested in the business," I agree that there is no difference in principle whether the reserve be lent outside or invested in the business, but I do not agree that the money must earn interest which must be credited to its real source. The real source of the money is the profit the plant has earned, and it would be absurd to increase the profit by interest which after all must come from more profit to be earned by the plant. As previously pointed out, the financial result of the undertaking is the same if an undertaking continues to pay interest on £100 and receives interest on £5 as when it repays £5 of this loan and only pays interest on £95, and it is to the interest on capital account that the interest should be credited. The paper bristles with controversial points and I do not agree that there is only one common method for the financier, the accountant, and the engineer. A renewal fund for providing the necessary money at the end of the physical life (page 154) is not absolutely necessary. If the money to buy the plant originally has been borrowed and has to be repaid by depreciation provided out of revenue, the course is left open, when the plant comes to be renewed, of re-borrowing and starting afresh. On the whole I do not agree with the statement in the last paragraph but one, that the sinking fund method fulfils all the requirements and the straight line method does not, because I think that the authors have started out on a wrong hypothesis and their conclusions are therefore illusory.

(The authors' reply to the discussion will be found on page [illegible]

DISCUSSION ON

"THE PARALLEL OPERATION OF ELECTRIC POWER STATIONS."*

YORKSHIRE LOCAL SECTION, 8 DECEMBER, 1916.

erd. Mr. J. **SHEPHERD**: I have no criticisms to offer on the paper. I have had experience of transmitting large amounts of power from one station to another and have never found any difficulty in exchanging power as required. The only point is that the power which can be transmitted depends very much on the size of the cable connecting the stations together. The instance I have in mind consisted of 6,600-volt three-phase generators driven by reciprocating engines; and with a 0·15 sq. in. 3-core cable and the stations a mile apart, if more than 1,500 kw. was transmitted the stations fell out of step. A cable of that size did not seem to allow sufficient current to flow to keep the stations in step when a certain power was exceeded. With two feeders of the same size 3,000 kw. could be transmitted before parallel running became impossible. With a more even turning-moment, i.e. with a turbine drive, the conditions would of course be very different.

ion. Mr. R. H. **CAMPION**: I think the author has almost started the battle of the systems again, apart from the question of what should be the standard periodicity. My experience of paralleling stations goes back over 20 years when we succeeded in paralleling a single-phase system at 100 periods with another system more than a mile away, and we used to be glad when the stations were disconnected, and left us with only the substation to supply. With the high periodicity I once saw the machines pulled in "dead out of phase." They held in, but the noise was rather startling. What I have noticed in other stations in connection with synchronous sets is that the stations which had synchronous motor-generators always had the best power factor. Of course that may be due to the load. They were certainly stations that were principally supplying cotton manufacturers. I was very interested to see that the author practically recommended only the rotary converter for interconnecting continuous-current stations. In connection with rotary converters I have noticed that they are ever so much better on 25 periods than on 50 periods. There does not seem to be half the experimental work required with 25 periods that there is with 50 periods. I must say that I think the particulars which the author has given us of the tests made at Salford as recently as last week will help considerably with the question of linking-up, provided that someone can be found to run the low power factors.

aw. Mr. J. H. **SHAW**: That part of the paper where the author deals with speed regulation is unnecessarily elaborated. It is not the custom to allow full load to be taken up by a station without manually adjusting the governors. As the load comes on, the governors are regulated to keep to the desired periodicity, consequently the calculations showing variations of load with different speed variations are not of much value.

Mr. Christianson. Mr. W. A. **CHRISTIANSON**: The interconnection of stations again raises the question of standardization of supply systems. There seems to be the general case of two or more stations of the same phase and frequency operating in parallel, and secondly the more complicated cases of the linking-up of irregular systems. Interconnection between three-phase e.h.t. stations, which can be carried out through the distribution systems or by independent interconnectors between the station busbars, is the most important and general case to be considered. The kernel of the whole subject of alternating-current station interconnection is voltage regulation and power factor, the former being dependent on the latter. Unless this matter receives careful attention the paralleling of stations will not give successful results. Apart from other obvious reasons, interconnection emphasizes the necessity of improving the power factor of the load on systems. With this done, the transmission problem will be very much easier and more economical. With regard to the results of paralleling the stations of Salford Corporation and the Lancashire Electric Power Company, mentioned by the author, the transmitted current was apparently at leading power factor, and therefore to the disadvantage of the receiving station, which would have to run sufficient plant to deal with the lagging current (assuming the power factor of the load on its system to be lagging, which is normally the case). These results are what one would expect, and would bear out my previous remarks on voltage regulation and power factor. In the case of a transmission line which I have in mind, calculation shows that the power factor of the transmitted load would be about 0·6 leading for equal voltage conditions at either end. Generally one cannot afford to work under such conditions and to deal with the heavy wattless currents resulting at the receiving end of the line. I think the author has attached too much importance to an aspect of governing which in practice does not really exist, mainly on account of the fact that the ratio of any load fluctuation to the total load of the system and the total capacity of the generating plant is usually small, and the division of load when paralleling in machines and at times of expected variation in the load is done by the governor regulators. Too fine governor regulation is not necessary on the majority of systems, and a moderate regulation gives more stability, which is desirable in the interconnection of stations to prevent load fluctuations between them. In these cases the regulation of the station as a whole must be taken. In the case of waste-heat stations deriving power from either live or exhaust steam an independent governor controlled by the available steam pressure is desirable, especially if the steam be subject to sudden variations; also in such stations fine speed regulation is certainly a disadvantage from the point of view of utilizing all the available steam without loss. With regard

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* Paper by Mr. J. S. Peck (see page 61).

Mr. [illegible]

[illegible] mentioned by the author is that of earthing at one station and automatic earth gaps at other [illegible] stations of the same voltage, which arrangement gives satisfactory results in practice. Where the interconnection is through transformers each system can of course operate its neutral, as desired, independent of the other. The interconnection of systems of different frequencies by means of two synchronous machines has certain limitations on account of the fixed speeds on either side which must be complied with. This could be got over by gearing, thereby permitting each machine to be most efficiently designed, besides [illegible] In conclusion, parallel running and interconnection are limited by the prevailing voltages in this country, and, if they have to be done on a large scale, higher pressures of the order of 50,000 volts or thereabouts will be necessary to overcome present limitations. This might be profitable on a large system intended for interconnection and where such was necessary, but whether the interconnection of many existing systems would bear such a cost is doubtful.

Mr. Pickersgill

Mr. A. Pickersgill: From the experiments and what has been deduced by Mr. Robertson at Salford, by the author, and by the Lancashire Power Company, it appears that there is no difficulty in connecting similar alternating-current stations in parallel. I myself do not see why there should be, if the link connecting the stations were large enough.

Mr. [illegible]

Mr. [illegible]: The paper should be of assistance to those who are considering the question of linking up two or more works situate some distance from each other, and although some of the points the author has made have been stated to be obvious, I think it is very useful to those engineers who have to tackle this question that these points should be brought to their notice. I may instance the point well brought in the difference in the speed regulation of two sets which may have to run in parallel. Such difference is not likely to have so detrimental an effect in the case of two sets in one station as it may have in connection with interlinking, where it is quite possible that some small undertakings with sets of 1,000-kw. or 1,500-kw. capacity may be linked up to others with sets of 10,000-kw. or 15,000-kw. capacity. There is little doubt that the interconnecting cables, at any rate those used in connection with the first attempts at linking up, will be tapped at several points between generating stations, and if under such conditions there were some considerable difference in the regulation of the machines, and those in the smaller works were of closer regulation than the larger ones, and a load of, say, 1,000 kw. were thrown on to the interconnecting trunk, to say the least the smaller works might be very seriously inconvenienced. Such being the case, the point is worth bearing in mind. [illegible] supply undertaking in the county has adopted a periodicity of 50, under these conditions interlinking can be easily carried [illegible] It may not, but at any rate I think it is a matter that should be very thoroughly looked into before any super-station is put down. Then again there is the question of voltage of transmission. Mr. Christianson has already alluded to this. He states that the pressure should be in the neighbourhood of 50,000 volts. That is also my opinion. I do not think much can be done, except for experimental work, with a voltage of 6,000, which has been adopted by the majority of works in the West Riding area. If the stations of the larger towns in this area are to be interconnected for the purpose of reducing the aggregate amount of stand-by plant necessary to be maintained, I think that the "Linking-up" Committee will have to consider what is the highest voltage that can be used with cables which can be purchased at the present time or in the immediate future. As far as I can find out from cable makers, they are not prepared to guarantee cables for use at a higher voltage than 33,000. They are prepared to make 40,000-volt cables, but they will want the customer to share the risks of breakdowns with them. If I remember rightly, just prior to the commencement of the War there was a proposal to use 50,000- or 60,000-volt cables in Berlin. I have, however, not heard whether a transmission system at this voltage with underground cables is now in use or not. Such information is now difficult to obtain. The tests that have recently been carried out at Salford are very useful, and the information given by the author with regard to them is most interesting. Many other such tests will have to be made in other localities. At the present time the Bradford undertaking is linked up with that of the Yorkshire Electric Power Company, but we have not yet attempted to parallel the two systems. We hope, however, to do so in the near future, and it will be interesting to see how the load divides between the two works. The paralleling of the systems has not yet been attempted owing to the connecting cables at the Bradford end being very much overloaded. With regard to earthed neutrals, I came to the conclusion, prior to hearing the author's remarks on the subject to-night, that the reactances or resistances suggested in the paper would hardly meet the case in view of the small amount of current necessary to interfere with telegraph and telephone circuits. Even in connection with the running of some rotary converters we are informed that the telephone system has been interfered with. I do not say that this interference was due to leakage currents—it was caused by induction—but I instance the fact as showing that it does not take very much to interfere with telegraph and telephone systems. I think that the use of step-up and step-down transformers is the simplest solution and will form the most practical way of getting over the earthed neutral difficulty, as, however large future generating stations may be, in all probability the pressure of generation will not exceed 6,000 or 10,000 volts, and therefore the trunk lines, if designed for pressures from 30,000 to 50,000 volts, will have to be fed through transformers. Arrangements can be made to earth these lines at one end only, and the neutral points of each of the 6,000- or 10,000-volt systems to which the transformers are connected can also be earthed.

Mr. Selv

Mr. W. M. Selvey: I have had occasion of late to go extensively into the question of power transmission, and I have one or two small points to raise. I think it would tend to clearness if one realized, in connecting two stations, for what primary purpose they are to be connected. If what is intended is an increase in security and the minimizing of spare plant, it amounts to running more generators on the same busbars. The link is then what I should term an "interconnector" between the two stations, and this heavy copper cable is practically an extension of the busbars. Such a coupling is not used primarily for the purpose of transmitting power, neither at any time is it used economically as regards the copper. It is a regulating device for smoothing out impulses and kicks, and it is an emergency device for exchanging power between the busbars of the stations. The question of linking up, as we know it to-day, is a somewhat different matter. It is an attempt of a big station to increase its economic factor by supplying the smaller station or stations on such terms as the smaller station itself cannot compete with. The link between them is of a different character from the interconnector, and I should prefer to call it a transmitter. If the transmitter is a long cable or an overhead line, it is necessary to consider that transmitter absolutely as though the smaller station were a consumer, estimating the capacity in proportion to the largest amount of power it is required to transmit. Unless economic use is made of that transmitter in the same sense as a cable supplying a customer, there is very little justification for it. Moreover, since the consumer or small station at the end of this transmitter must have his own voltage, generally speaking it is not sufficient to have a plain conductor, but a transformer has to be added. Also if the transmitter is of any length (and I have found in making many calculations that anything like 10 miles must be considered a considerable length in this country) it is necessary to have at one end, if not at the other as well, some form of voltage regulation so that the small station may have quite an independent voltage. This leads up to the question of regulating types of transformers, the modern types of which the author has illustrated, the difficulties being largely connected with moving contacts. Further, there is not only a question of linking up two stations, which is what many speakers have dwelt on, but also a question of linking up a number of stations. When there are more than two, quite different problems arise. Disturbances have occurred in my own experience with isolated stations already linked up, and there was considerable difficulty owing to the forced redistribution of load. It results in this: whenever any trouble occurs or any heavy load comes on, it always falls on the biggest station. It seems to me that the result of economically linking up power stations in any district will always be that one master station will do the bulk of the work and take the bulk of the responsibility, while the smaller stations will run at 100 per cent load factor for such time as they are required. This will probably be an 8 to 12-hour daytime shift, according to when the peaks of load occur in the district. These small stations would take practically no responsibility.

Mr. W. HARTNELL: The economical advantages of compulsorily linking up over wide areas the electric generating stations, existing or expectant, appear to be so great that compulsion by Act of Parliament is being seriously proposed. On the other hand, the electrical diversity has seemed at first sight to render the proposal impracticable. This paper, coming as it does from a man of practical experience and scientific attainments, is of great value as a pioneer paper showing how intercommunication can be made under almost any circumstances, so far as electrical variations of supply are concerned. To complete such extensive intercommunication with simplicity and economy and for great final efficiency, the mains for the sub-districts should be at once determined and standardized (such as three-phase, 50 periods, 10,000 volts) and all intercommunication be made to the standard. Outline plans for the scheduled area should be made at the public expense and all necessary wayleaves obtained by law.

Mr. N. STELL: One of the great factors, as I understand it, in the electrical world is the question of cables. The life of a cable to a power engineer is a very considerable point. Nothing has been said in this paper as to the effect on the cables—I mean the mains of interconnecting stations—by, say, such things as the incorrect adjustment from one station to another, which might cause a very serious breakdown in the cable, and, as is suggested by the author, might cause a serious breakdown in the group of stations. I think it would be of interest if information could be given on these points, and it might be materially helpful to manufacturers and engineers to know what is the best kind of cable to use for the work and also the best kind of insulation.

Mr. J. E. STORR: The points which strike me most forcibly in the consideration of linking-up schemes are the necessity of higher voltages and the correction of power factor. Until we can get forward with transmission at higher pressures than the existing 6,000 or 10,000 volts, not much headway will be made. I think that perhaps too much consideration has been given to the power-house point of view. The matter of interconnected running will, I consider, have to be settled on the outside system. The higher pressure cables will reduce the cable losses, the regulation will be improved, and with improvement of power factor away from the generating station, the stability of interconnection will be more secure. Mr. Roles has mentioned a maximum voltage of 30,000 as a possibility to-day. I think higher voltages are actually available to us even now. The cable manufacturers are making cables to withstand acute tests for a working pressure of 30,000 to 33,000 volts, but the cable will withstand, and probably work satisfactory at, 50,000 volts if the purchaser's tests at the factory were more reasonable, particularly the bending tests, and the final reliance placed upon a reasonable over-pressure test after laying. I suggest that with higher voltages and some form of power-factor correction we shall be able the more effectively to deal with the problem of interconnected running and exchange loads which will be worth while.

Mr. W. LANG: I was interested in Mr. Campion's remarks. In connection with this very important question now before the electrical world, I think that so much importance may be attached to it that one cannot "see the wood for the trees," and that one may lose sight of the fact that the cost of interconnecting, and the troubles always incidental to any attempt to connect different stations together, may not be worth the bother. The money spent and the effort exerted in that direction might be used to better advantage if it were admitted that in certain small stations much better results would be obtained by using such stations simply as distributing centres than by [illegible] with the object of getting the 100 per cent load factor to which Mr. Selvey referred.

Mr. H. [illegible]: The parallel operation of stations carries with it no insurmountable difficulties [illegible] that such linking up is only justifiable if each authority is benefited thereby. The question of voltage regulators and power factor and frequency is one of great moment, and each scheme will have to be dealt with and considered on its merits. Automatic devices will doubtless be required at each station, so that as far as possible regulation of voltage with load will result. Protective gear is also essential. The matter of transmitting energy in either direction [illegible] trol engineer being appointed. Suitable recording apparatus will also be desirable to satisfy various authorities. The subject of earthed neutrals raised by the author, and more especially the question of high-frequency and other circulating currents, appears to be on a par with the line of thought so often expressed in the early tramway days as regards electrolytic action on pipes from stray currents. I think the possible trouble is greatly magnified. I have in mind several cases of earthing star points at many places, also instances where neutrals were crossed by mistake for long periods, resulting in heavy currents flowing, yet no complaints were made by the Post Office engineers and as far as I know no damage was done to anything. It must be remembered that great advances have been made, not only by generator designers in eliminating higher harmonics, but also by Post Office engineers in the design of cables and mechanism, so that electrostatic and earth-current electromagnetic [illegible] cables are invariably run in cast-iron pipes [illegible] cables are lead covered, I think that induction troubles and magnetic effects are dissipated or confined to the magnetic field around the iron pipes. I should be glad if the author would cite cases in England where telephone and telegraph circuits have been in- [illegible] place, whether with overhead or underground transmis[illegible] I think that where transformers are inserted in the [illegible]g circuits no trouble need be apprehended. In Sheffield we have run an 11,200-volt three-phase station in parallel with a two-phase 2,100-volt station for about 10 years with satisfactory results. Scott-connected transformers are installed at each station, with a transformer booster at the one and a synchronous motor-generator at [illegible] so that load can be varied within reasonable [illegible] tions already raised as to [illegible] ntinuous current is required [illegible] verters, which are most useful where [illegible]

Mr. Yerbury.

that the capacity of the generating plant and cables would be increased and the losses in generation and distribution reduced, a reasonable concession of, say, 5 per cent should be made in the price per unit supplied to these consumers. I think that rotary converters will take a prominent part in interconnecting systems in the future.

Mr. J. S. Peck (in reply): Mr. Shepherd's information regarding the limiting load which could be transmitted through a cable of a certain cross-section is quite interesting, though, as he points out, the limits might be very different in the case of turbine-driven machinery. Mr. Pe

Mr. Shaw thinks that the part of my paper dealing with speed regulation is unnecessarily elaborate, as it is not the custom to allow full load to be taken up by a station without adjusting the governors by hand. It is true that in the majority of cases, and particularly in the case of large stations, it is possible to adjust the governors from time to time in order to keep the frequency constant and to distribute the load among the different machines as desired, and under these conditions it is possible to use a very much smaller frequency changer for linking up two systems than in the case where load fluctuations are so rapid that hand regulation is not possible. I endeavoured to point this out in the paper, and my purpose was to show the maximum load which could be thrown on the interconnecting link where load fluctuations were too rapid to admit of hand adjustment.

Mr. Christianson makes a number of remarks with reference to governor settings and speed regulation, with which I am in general agreement. His suggestion as to the use of gearing, in order to obtain the correct speed ratio for synchronous frequency changers, is one which has been made previously, and I believe under certain conditions it offers a number of advantages. The great objection is the high cost of gears. With regard to high voltage for use on the interconnecting lines, I have already discussed this point in replying to previous speakers.

Mr. Selvey raises a number of very interesting points, but most of them are of a commercial rather than engineering nature, and I think they have been treated rather fully in some of the reports made by the "Linking-up" Committees.

Mr. Stell asks for information regarding cables. I am afraid I cannot give him much information on this point, as I think that in general the engineers responsible for distribution have had much more experience with cables than have the manufacturers of electrical machinery.

Mr. Yerbury's remarks with regard to the earthing of neutral points at different points of a system are quite interesting. It is, however, a rule established by the Board of Trade that a system should not be earthed at more than one point, and I imagine there was some reason for establishing this rule. I know of one recent case where very serious trouble was caused to telephone or telegraph circuits due to high-frequency currents flowing through earth between two stations. This trouble occurred in London within a couple of years, and while I have not full particulars I have no doubt Mr. Yerbury could obtain them if he cares to do so.

Newcastle Local Section, 11 December, 1916.

Mr. Clothier.

Mr. H. W. **Clothier**: The author has spoken of coming to Newcastle with coals, and really it does seem that development in the matter of linking up power stations is further advanced in this district than elsewhere, for there are no less than 16 power stations interconnected and running continuously in parallel on one system. An important detail is the design of switchgear, as it involves an increase in the power dealt with, consequently the work done by the gear in breaking short-circuit currents becomes heavier. In America it would appear to be the practice to use definite time-limit devices on the power-station control gear for the expressed purpose of reducing the stress on a switch when breaking the heavy short-circuit currents. This time-limit is adjusted so as to delay the operation of the switch until the current has had time to die down to the sustained short-circuit current stage. On the other hand, in this district the objective has always been to intercept the short-circuit current by, as nearly as possible, an instantaneous break, having the “continuity of supply” as a first consideration. Will the author give us information as to the experience in the States in regard to the effect of time-limit devices on the “continuity of supply”? Does not the practice savour of the switch being spared at the expense of the consumers? What length of time is necessary between the occurrence of a fault and the actual rupture at the switch sparking-contacts, in order to prevent the fault remaining on the system long enough to risk the synchronous plant running out of step (and incidentally to prevent the operation of no-voltage devices sometimes used on the consumer's plant)? It has been estimated, on a system such as that on the North-East coast, at 0·5 second; it may be much less, and would of course be affected by the nature and relative position of the fault in respect to the plant. The conditions here, anyhow, do not allow any appreciable margin of time for the introduction of “definite,” “inverse,” or “fuse” time-limits. For even when due regard is given in design to the maximum speed of automatic operation, it is not usual to commence the actual break in less than 0·15 second, this time including that occupied by the relay, the trip coil, and the switch mechanism, up to the moment of the separation of the sparking contacts. On a system where the characteristics of the generating plant are such that the initial instantaneous short-circuit current is 25 times the aggregate r.m.s. normal full-load current, the instantaneous current at 0·15 second (periodicity 40) is about 12 times the normal. Whereas a further delay of 1 or 2 seconds' duration allows the waves to die down to the sustained short-circuit current, i.e. to, say, 3 times the normal. The resultant reduction is a considerable factor in the strength of the switch; but it is questionable whether it is wise to take advantage of it, particularly if it is taken at the cost of jeopardizing the supply to the consumers. Moreover, when considering the strength of switches, there is another point to be taken into account, namely, that on some occasions (remote they may be) a switch may be called upon to break circuit between the initial short-circuit current waves. For instance, a fault starts between one phase and earth, the current limited by the resistance to the neutral point of the generators, at the initial stage is not seriously heavy. But suppose the fault grows and develops into a short-circuit between phases simultaneously with the actual separation of the switch contacts, then the switch has to clear under the most severe condition. Time-limit devices are no safeguard against such a contingency. To sum up, therefore, when considering switchgear in relation to linking up it is advisable to bear in mind that the stresses on the switches on most occasions may be reduced materially by the introduction of a short time-limit, the amount being determined by the limit to which the synchronous plant will go without running out of step. At the same time it must not be taken for granted that this precaution alone renders the switch entirely immune from having to interrupt the circuit between the worst impulses. The only safe way is to ensure that each switch will be made capable of withstanding the maximum stresses that can appertain on breaking short-circuits under the heaviest momentary conditions within its sphere of action.

Mr. Beard.

Mr. J. R. **Beard**: In previons discussions of this paper the author has been somewhat severely criticized and numerous supposed difficulties in parallel running have been put forward. I think therefore that the best service we can do to him and to the electricity supply industry in general is to emphasize the fact that parallel operation over extensive areas has been an accomplished fact on the North-East coast for many years. While this has already been mentioned, I think that many engineers in other parts of the country do not quite appreciate that the load on the North-East coast interconnected system with its 16 or so power stations scattered over the area verges on 100,000 kw. and accounts for about one-fifth of the total electricity generated in public supply stations in the United Kingdom. So far as parallel operation of systems of the same frequency is concerned this cannot but be conclusive. This district can claim to have been the first in this country where parallel operation of power stations was carried into effect. In 1904 Neptune Bank and Carville power stations were run in parallel, the plant of the former consisting of low-speed reciprocating sets and that of the latter of steam turbines; in 1905 a station some 8 miles distant was coupled up and so far as I am aware no trouble has ever been experienced in the parallel operation of these stations. In 1912 the big stride was taken of running power stations on the Tees in parallel with power stations on the Tyne, the nearest route between them being 42 miles. At one end power was generated at 6,000 volts, transmitted some distance at this pressure, and stepped up to 20,000 volts for the main transmission, after which it was stepped down to 11,000 volts, transmitted further at this pressure and again stepped down to 3,000 volts. As a matter of interest I have worked out on the basis of Appendix 1 of the paper some figures relating to this case of parallel operation. The capacity of the plant at the Tees was about 6,000 kw. and on the Tyne about 30,000 kw. The total resistance per phase between the stations was 23 ohms and the reactance 18·2 ohms, of which 3·2 was represented by the alternators themselves. Assuming that the synchronizing power would have been 100 per cent if the whole of the plant had been concentrated in a single power station, the synchronizing power under the

Mr. Beard

[illegible] with the plant in two sections [illegible] per cent. In this particular instance there is no doubt that the limit of successful [illegible] approached as although no actual trouble was experienced there was swinging on all the instruments and the swinging could actually be detected in the humming of the plant. From tests which were made it was found that the swinging was much worse with certain machines in commission than with others, but whatever the cause of the swing, the fact that it could be produced was evidence that the synchronizing power was very low. At the time consideration was given to taking steps to reduce the swinging, but fortunately there was no need for this, as due to the natural growth of the system the amount of copper between the two systems was largely increased and the trouble soon died away. [illegible] attention to the fact that distant stations should be linked up through as much copper as possible and not through one or two special interconnectors. In this district frequency changers have not been much used up to the present, although two or three have been installed in connection with a supply to a large colliery system. Fortunately when systems of different frequency have in the past been linked up with the main system it has been possible to convert the smaller systems to the standard frequency without much trouble, and this undoubtedly makes the simpler job when it can be financially justified. I think, however, a safe deduction from the paper is that there are no serious technical difficulties in the use of frequency changers provided they are not too small relatively to the smaller system to which they are linked up, and that their use is a question of balancing their capital cost and losses against the reduction in standby plant and the [illegible] generating electricity in the most economical [illegible]. As the maximum synchronizing power of [illegible] minimum size of set which it is permissible to use, it might be worth while to pay careful attention to installing frequency changers in such positions on the network as to give the maximum synchronizing power. Generally speaking this would appear to be when the frequency changers are [illegible] way between the two generating plants, whereas the usual practice seems to be to install them in one of the generating stations. Turning to Fig. 1 of the paper, showing a diagram of connections of a voltage regulator, I notice that it is arranged to regulate on two phases only; our practice has been to regulate on all three phases, as otherwise the neutral point on one side would be displaced. I should like to have seen a little more [illegible] In fact only a few years ago it was [illegible] of apparatus. There are a number of points in connection [illegible] in earthing at several points, and I think the fear that such a course would result in interference with telegraph and telephone circuits is due to a large extent to a misunderstanding of the effect of such multiple earthing. When the neutral is earthed, whether at one or more points, heavy currents must flow under certain fault conditions, and these currents must be the determining factor in causing disturbance to telegraph or telephone systems. We know that in the great majority of cases no trouble does arise under such fault conditions and, if this is so, surely the relatively small triple-frequency currents which might flow between the various earthed neutrals would be still less likely to cause any trouble. On the other hand, multiple earthing is in many ways beneficial in preventing interference with telegraph and telephone circuits, as it ensures that faults on feeders are of sufficiently low resistance to operate the protective apparatus under the most onerous conditions and with a minimum of delay. Further, in such a case the fault current will usually tend to divide in several directions instead of being all bunched in a single direction. With modern machines the wave-form approximates so closely to the true sine wave that the values of the triple-frequency currents will be very small. They can, however, be still further reduced if an earthing reactance is used in place of an earthing resistance. If the two were both designed to allow the same fault current to pass at normal frequency it is obvious that the reactance would interpose three times the obstruction to the circulation of the triple-frequency currents. If instead of earthing the neutrals of machines or step-up transformers the neutral of the system is earthed through special earthing reactances connected direct through switches to the busbars of the stations, I believe on three-phase systems there is no tendency for triple-frequency currents to be produced between the neutral points of such reactances. This follows because triple-harmonic voltages do not normally exist in the line voltages of ordinary three-phase systems, but only in the phase voltages of the generating plant. If the author can conclusively confirm this it would be an important argument in favour of modifying the existing restrictions on the earthing of the neutral so as to permit of multiple earthing, provided it was carried out in such a way as to avoid circulating currents under normal [illegible]

Mr. C. TURNBULL: The problem which will cause most difficulty is where a comparatively small amount of power is transmitted from one system to another. Suppose that we have two stations, one, say, of 10,000 kw. and the other of 5,000 kw., the frequencies being respectively 50 and 40 periods. It is necessary to transmit 1,000 kw. from one system to the other. The problem which arises is, how can the 1,000-kw. motor-generator keep the 10,000-kw. and the 5,000-kw. stations in step? If the motor-generator is synchronous throughout, it becomes a difficult task to "phase in" the second machine, and when in phase the 1,000-kw. capacity would be insufficient to hold the two stations in step in all circumstances. The use of an induction motor would overcome part of the trouble, especially with a phase advancer to bring up the power factor, but in this case it would be necessary to adjust the frequency of at any rate one station, from time to time, to ensure that the right amount of power was transmitted. This would not always be practicable, especially if two or three stations were linked up. A motor-generator has been introduced by an English company in which the stator is arranged on bearings, so that it can be rotated by a motor which gives the torque required to transmit any particular power. This automatically compensates for any variation in the periodicities of the two systems. The motor-generator can be synchronous throughout, or one end can be induction, as may be required. If the machine proves reliable, it should overcome all difficulties and greatly help progress in linking up.

Mr. J. W. Jackson: A point which calls for special attention in connection with this paper is the desirability of perfecting the mechanical features of generator governors so as to ensure as far as possible an even turning moment. The previous speaker mentioned the difficulty of getting one system in parallel with another. It is known that on some plants the governor gear does not ensure an even turning moment, i.e. a governor gear may be so good from one point of view that it controls the mean speed of the generating plant within 2 per cent up or down, and, although this may be very excellent, it is of greater importance to ensure that the governor control is free from periodic variation. Acute variations may be set up through badly cut governor gear-wheels, or slackness of governor bearings, or unsuitable damping appliances, and although all these faults may be present, the mean speed can be kept within the above-mentioned limits and yet the disturbance to the system or systems may be so serious as to prevent two sections being run in parallel, thereby causing the electrical specialist to hunt all over the lines for those peculiar demons, such as harmonics, resonance, distortion of wave-form, etc. Some or all of these may be present, and undoubtedly are, but as a rule they can be entirely removed by attending to such a tiny detail as badly cut gear wheels on the governor gear, etc. Now that electrical generators have attained such a high degree of excellence the above would appear to be a more frequent cause of trouble than has been the case in the past. It is very interesting but surprising to hear that engineers connected with big power plants profess doubt about the value of running large electrical systems in parallel, or even the mere possibility of doing so. We on the North-East coast have seen this scheme worked out, and have known it in operation for many years. It has in fact become such a natural thing with us that we cannot understand why other electrical undertakings are not doing likewise. At the same time, I remember some 1,500-kw. simple compound engines driving electrical generators which were required to run in parallel with some four-cylinder engines, and the trouble between the two sets of engines was indeed acute, and the electrical troubles on that system were very great. These, however, were undoubtedly set up by an inherent fault in the design of the cross compound engine as apart from the governor scheme. Charging arrangements for electrical cables, spark gaps, and a great amount of most complicated, intricate, and difficult apparatus had to be used. It is understood, however, that the trouble has now been entirely overcome by the installation of turbine-driven generators. Another point which appears to cause some engineers a good deal of trouble is that of sharing the load between the various systems. This cannot be described as any trouble at all on the North-East coast, as the generating stations in the respective areas carry, without any difficulty whatever, the amount of load which it can be predetermined they should carry, although some of the power stations may be as far as 40 miles apart. There is still another point in this paper which is of interest, and that is the use of frequency changers. It would appear that synchronous frequency changers are the most desirable, because it appears to be possible with only this type of machine to interchange load between the respective systems without causing any serious variation in the speed of any of the systems, as would be the case if asynchronous machinery were adopted. Mr. Jackson.

Mr. R. M. Longman: I should like to join with Mr. Jackson in stating that one of the most important questions in connection with parallel operation is the governors. On Tees-side when first linked up with the stations on the Tyne it was noticed that when a certain governor was adjusted the swinging already mentioned was very much reduced. Swinging always shows most on indicating wattmeters and power-factor meters, but it is now practically negligible. Of course, all the prime movers are steam turbines. Trouble may be experienced in connecting up small stations where reciprocating sets are used, but this will disappear with the reciprocating sets. In linking up stations of different capacities, or where the plant and switchgear are not of sound mechanical construction, in the case of a fault on such apparatus considerable damage is likely to occur. In the satisfactory operation of small stations much will depend on the setting of the protective gear. One of the chief items in the satisfactory operation of power stations is a reliable straight-through telephone connection between the stations concerned. In regard to the earthing of the neutral, I would prefer the scheme suggested in section (*d*) on page 64, as I consider such an arrangement to be necessary to keep down the current in the case of a bad fault. The practice is generally adopted of earthing only one power station, and this station may be isolated by a bad fault; trouble may then be experienced when closing up again with the fault still on. I think it would be satisfactory to run with two points earthed through resistances or reactances, but preferably reactances. It is advisable to run the different stations at the same power factor when possible, and a power-factor indicator is therefore a very useful instrument to have on an interconnector between two stations. I agree with Mr. Beard that the diagram on page 62 hardly seems to be the correct thing to use for transformer regulators. Induction regulators, I suppose, are impracticable on large systems; it is advisable to use transformer regulators and to run them at a lower voltage. They stand up much better if run at 2,000 or 3,000 volts than at 20,000 volts, and the insulation between tappings, etc., should be made for 10 times the normal voltage expected. We find in this area that the frequency of the system is marvellously constant. From the discussions before some of the other Local Sections it appears that the engineers are rather fearful of linking up. In some cases it may be advantageous to use an induction set for a frequency changer and employ a phase advancer of some sort, so as to run the induction motor at a good power factor. Mr. Longman.

Mr. L. H. A. Carr: On page 64 the author states, among the disadvantages of the synchronous motor- Mr. Carr.

[illegible] that each machine must be synchronized with [illegible] espe- cially with certain ratios between the numbers of poles. It would be good to have an explanation why certain numbers of poles should cause more difficulty than others. I remember two such sets supplied to a Canadian installation where the generator stator of each set was capable of being rocked, and when the second machine was started up it was merely necessary to rock the stator into the no-load position for synchronizing, and then rocking it back to take up its share of the load, due to the lag between the no-load and full-load positions. One difficulty that might occur with a synchronous-synchronous set under special conditions is as follows. Suppose that the small power station were shut down, and that all its load were being supplied through the synchronous motor-alternator set; then if the load were varying, it is possible to conceive that this variation might strike the natural period of vibration of the set, with the result that the surging would be so great as to bring out the circuit-breakers and shut the plant down. In a case of this sort the only remedy would be to replace the synchronous motors by induction motors; and though it may appear far-fetched to expect an occurrence of this sort, yet with certain types of intermittent load the above trouble may easily be experienced.

Mr. R. W. Gregory: It comes as a surprise to us who know something of the working of the power companies in this district to hear that doubts have been expressed upon the possibility of running in parallel different power stations generating at the same frequency. There are in this district at the present moment some [illegible] generating stations running in parallel. These generating stations are of various capacities, from [illegible] to [illegible] kw. They contain generators of various types, generating at different voltages with varying transformers and regulation. The distance between extreme generating stations is approximately [illegible] miles. It is interesting to note that the number of [illegible] voltage regulators used to run these [illegible] generating stations in parallel is not more than [illegible]. If, therefore, experience and practice are guides at all it is established that the parallel running of generating stations of common frequency is sound and simple engineering. The main interest in the paper is the consideration of the problem of paralleling stations generating at different frequencies. Mr. Beard has emphasized the necessity of keeping down the resistance of the interconnectors between generating stations if parallel running is to be successful, and it seems, therefore, that instead of collecting the frequency-changing plant in one place it would be simpler to use a number of smaller sized machines totalling in capacity that required for safe parallel running and to place these machines one at each of the points where the networks fed by the power stations to be parallel come near together (see Fig. J). This arrangement would give: (*a*) minimum cost of interconnection, (*b*) low resistance of interconnectors, and (*c*) large synchronizing forces.

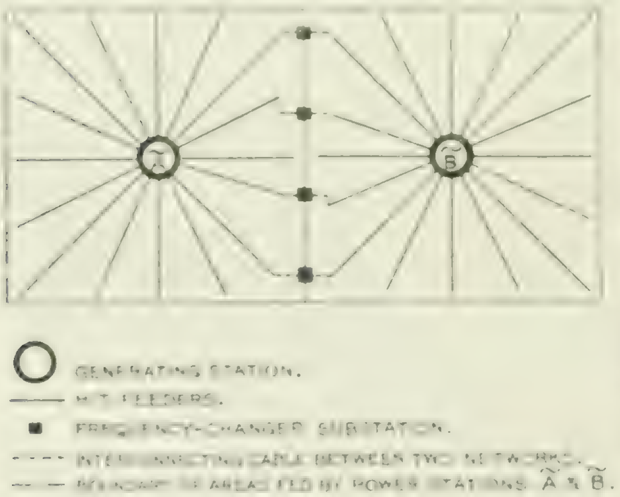
A
B
GENERATING STATION.
H.T. FEEDERS.
FREQUENCY-CHANGER SUBSTATION.
INTERCONNECTING CABLE BETWEEN TWO NETWORKS.
BOUNDARY OF AREAS FED BY POWER STATIONS Ã & B̃.

FIG. J.

Mr. Gregory.

Mr. G. L. Porter: Among the more obvious advantages of linking up power stations are: (1) To take advantage of diversity in loads; (2) to pool spare plant; (3) to load up the more economical plant. The third is really of the greatest national importance but is hardly a technical question. If in any given case of linking up much is gained from load diversity, it is evident that the areas concerned either have not been properly developed or else were too small or too specialized for a really efficient local supply. It is also clear that the larger and better developed the local power systems are, the less the advantage gained under this head from interconnection. The advantage gained by pooling spare plant does not decrease with greater degrees of interconnection. The latter—like insurance—spreads the risk. From this point of view, plant in a power station may be divided into two classes, namely, (*a*) boilers and most auxiliaries, which affect the kw. capacity of the station, (*b*) generators, etc., which affect the k.v.a. capacity of the station. Especially with much reactance (overhead line and transformers) in the interconnector, it is much easier to transmit kilowatts from one station to another than kilovolt-amperes at ordinary power factors. Thus a booster might be required in an interconnector installed due to shortage of generating plant, whereas the same interconnector might take care of low water troubles in summer without such assistance. Engineers in the north are so accustomed to running power stations in parallel that the author's remarks regarding automatic speed regulation seem rather elementary. Unfortunately he stops just short of where such difficulties as there are really begin. The action of turbine governors can be arranged as required, it is the hand regulation that is difficult to manage even where all the stations are under the one authority. In practice only one station—preferably the largest—may do hand regulation of the speed as such; the others must do load regulation. The load on the interconnector should be the guide to such regulation. Unfortunately this is very difficult to arrange where the interconnector does not run direct into the power station. As mentioned by the author, there is a similar difficulty in voltage regulation. If the interconnector is of low reactance and without a booster, only one station may regulate the voltage while the other does power-factor control, preferable by the power factor of the interconnector. If there is a booster this is best used for power-factor control while the voltages are

Mr Porte

orter. regulated in the usual way by field rheostats. It is probable that an automatic booster on the interconnector would simplify matters very much if it could be controlled by a power-factor-indicator movement instead of by the usual voltmeter one. I should like to know the author's opinion of this.

eck. Mr. J. S. Peck (*in reply*): Mr. Clothier has raised a number of very interesting points in connection with switchgear for use on large power stations, but as these remarks apply to oil switches in general, without reference to parallel operation, I shall not attempt to answer them in detail. I think the tendency to-day in all countries is to try and isolate a defective section of a system while the defect is in the incipient stage, and before a dead short-circuit has occurred. This I think is the great advantage in the Merz-Price and other types of balanced protective apparatus. Where a defective section cannot be isolated before the dead short-circuit has occurred, a short, definite time-limit will make easier the operating conditions of the switch, provided that the maximum current is determined by the instantaneous short-circuit current of the generators and not by inductance or resistance in the feeders. Even with the quickest-acting relays and switch mechanism it is practically impossible to open a switch before the maximum short-circuit current of the generators has fallen to a very considerable extent. It is extremely difficult to say how long a time is required for synchronous apparatus to fall out of step when a short-circuit occurs. Assuming that a short-circuit occurs on the busbars, the voltage falls to zero, and synchronous apparatus ordinarily supplied from the busbars will feed back into the short-circuit. If the short-circuit is not interrupted, the regenerating apparatus will come to rest very quickly. On the other hand, the speed of the generators will be maintained at practically normal value, except for the slight drop in speed due to the heavy torque produced by the short-circuit current. If the generators and synchronous apparatus slowed down at the same rate, the synchronous machines would hold in step after the short-circuit had been removed and the voltage brought back to normal. It is obvious that there are a large number of variables involved, such as the flywheel effect of generators and other synchronous machines, the position of the short-circuit on the system, the reactance and resistance between the generators and the short-circuit, and between the point of short-circuit and the synchronous machines, etc., and accurate calculations will be extremely difficult.

Mr. Beard gives some most interesting information regarding the progress and present condition of parallel operation on the North-East coast, and it is of interest to know that so many stations have been linked up, and that the operating difficulties have been very few. The use of a voltage regulator, such as shown in Fig. 1, has been discussed in connection with the remarks of a previous speaker. Mr. Beard feels that the operating conditions are improved by earthing the neutral point at more than one station, and he does not anticipate trouble with the Post Office even when no special precautions are taken. The fact that trouble is experienced in some cases where very small currents flow through the earth, and is not experienced in other cases where much heavier currents flow, would seem to point to the fact that some telephone and telegraph circuits are much more susceptible to the influence of earth currents than are others. It is well known that a telephone circuit with an earth return is extremely sensitive, whereas a circuit with a metallic return, especially where the two wires of the circuit are twisted together (as in a cable), are not so subject to outside disturbances. Mr. Beard makes a suggestion of earthing through special reactances connected to the busbars, and I think this is a matter well worth further investigation, but Mr. Trotter says: "If we are going to limit them (earth currents) from the point of view of the Post Office, we may have to come down to some micro-milli-amperes." If we are to work to such limits, it is of course useless to think of earthing at more than one point even if reactances are used for earthing. Mr. Peck.

Mr. Turnbull says, regarding frequency changers, that an English company has introduced a machine in which both stator and rotor are allowed to revolve in order to secure any desired frequency. Machines of this type have never met with great success, on account of the mechanical difficulties involved in their construction.

Mr. Jackson emphasizes the necessity for proper governing gear with reference to prime movers where parallel operation is required. He also points out that there has been no difficulty on the North-East coast in getting the numerous stations to divide their load as required.

Mr. Longman gives interesting information regarding operating experience on the North-East coast.

Mr. Carr asks for information regarding frequency changers. The questions which he asks will probably be fully treated in a paper on this subject which is shortly to be read before the Institution.

Mr. Gregory points out that 14 feeder regulators are sufficient for properly dividing the load among the 16 interconnected power stations on the Newcastle system. Mr. Gregory also makes some suggestions as to the best positions in which to locate the frequency changers for linking up two systems. I believe the arrangement he shows would be quite satisfactory provided that extra attendance were not required for operating the rotating apparatus in the different frequency-changer substations.

Mr. Porter points out that cases may arise where it will be desirable that some stations should deliver the maximum kilowatts which they can produce into the system at unity power factor. In other cases, stations will be required to feed the maximum amount of magnetizing current into the system without special reference to the number of kilowatts which they can deliver, or, to express it in another way, some stations may be known as kw. stations and others as k.v.a. stations. The determining factors will be boiler capacity and generator capacity.

SCOTTISH LOCAL SECTION, 12 DECEMBER, 1916.

Mr. Lackie. Mr. W. W. LACKIE: The parallel operation of electric power stations is a matter of which we are to hear more in the near future, and this paper is a welcome and able introduction to the subject. Glasgow is one of the cities guilty of having separate stations for traction and power, but I am glad to say that these stations have for a number of years been run in parallel when required. I feel that we in Glasgow have had considerable experience in linking up. In 1898 the Corporation purchased the Kelvinside Company's undertaking, and in 1912 the Partick and Govan stations were taken over by the Corporation and linked up with the Glasgow system. Although the pressure of supply was not the same in all cases, it was not very long before the consumers' lamps and wiring were changed over and brought into line with the Glasgow pressure, and the Partick and Govan stations were then run in parallel with the Glasgow stations when required. In the case of the Kelvinside station it supplied its own area from 3 p.m. to 11 p.m. when the load was considerable, but during the remaining 16 hours of the day the load was drawn from the main power stations. Kelvinside is now a substation, still run, however, in the same way as I have just described. Govan and Partick stations would have undergone similar treatment had not the War intervened and stopped operations. What I want to indicate is that in the case of stations of less that 3,000 kw., which are to be linked up with large power stations, it will be found a commercially practicable proposal to change consumers' lamps and apparatus to a pressure and periodicity to suit the larger power station. According to the *Electrical Times* there are 14 local authorities and 14 supply companies in the London area supplying electricity. Twelve of these concerns have each under 3,000 kw. of maximum demand; five of them are between 3,000 and 5,000 kw.; three are between 5,000 and 10,000 kw.; and five are between 11,000 and 20,000 kw. There is no doubt that the twelve 3,000-kw. stations could and should be tackled first, which would practically halve the number of generating stations in London. It appears to me that for many years linking up will be limited to an exchange of energy at times of light load, i.e. at week-ends and on holidays, and in some cases for all-night loads. Consequently, when apparatus has to be installed it will not be necessary to have it of anything like the capacity of either of the stations linked up. When Port Dundas, St. Andrews Cross, and Pinkston power stations were linked up, fortunately we had all the stations of the same voltage and periodicity and little trouble was experienced. The plant [illegible] Mr. [illegible] has told me that he had one or two adjustments to make before all went smoothly, but there was nothing of a serious nature. The three stations are now connected together and run in parallel at times of light load, and they are interconnected with [illegible] between Pinkston and Port Dundas [illegible] and between Pinkston and St. Andrews Cross [illegible] All the stations [illegible] said to be of different capacities and yet we have no difficulty in arranging the load amongst them. I cannot say what the speed regulation of the reciprocating engines at Pinkston was, but I should think it was very different from that obtained from turbine-driven sets. The author has very clearly put before us the apparatus available for interconnecting stations of different periodicities and voltages. With reference to interconnecting through rotary converters as described on page 67, am I right in thinking that if a rotary converter is to be used both ways, i.e. if at one part of the day it receives alternating current and delivers continuous current, while at another part of the day the process is reversed, such a converter must be supplied with independent field excitation if the machine is to be anything like stable? This arrangement for using a rotary converter both ways is at present adopted by the Falkirk Electricity Department.

Mr. F. H. WHYSALL: The author has referred to two classes of engineers: one class who think linking-up such a simple problem that no paper is necessary, and another class who have grave doubts as to the possibility of linking up stations satisfactorily. His paper is the answer to both. Personally I am inclined to favour the engineers who see very little difficulty in the problem rather than the other section. It is a fact that many central stations are being satisfactorily operated when linked up to each other without any of the devices which the author has described. In Greenock we are interconnected with a small hydro-electric scheme. This linking-up was carried out at very short notice without any special apparatus, and I can say that in this particular instance we have had no difficulty in operation. We have been able to keep the other supply going when they were short of water, and we are now running all day long in parallel for the purpose of governing their speed. This they find to be a great benefit, and I may add that we have no difficulty in maintaining unity power factor.

In connection with the linking-up of two undertakings having different periodicities, the author referred to a point of which I have some little experience, namely, that with an induction motor as a generator, it would be necessary to have some form of synchronous apparatus running in parallel with the induction motor which is acting as a generator. When Stuart-street station, Manchester, was first started, a steam exciter and an induction-motor exciter set were used to supply the very small amount of current required during the night. This avoided the necessity of running a large generating set and effected a considerable saving. A synchronous motor-generator at one of the substations was kept on the system and instructions were given that this should be kept over-excited, and I remember on one occasion these instructions were neglected with disastrous results. I favour the synchronous motor-generator and I think we should be prepared to tackle its disadvantages. Mr. Lackie has pointed out that the interchanges of current between systems are more likely to take place during week-ends and over-night, when certain of these disadvantages would not be operative. In short, I am of the opinion that the technical difficulties in connection with the problem of linking up would be easily dealt with and commercial considerations seem to me to present greater difficulties.

Mr. Page.

Mr. A. Page: I am glad that the author has amplified what he has written in the paper, as I got the impression when I first read it that to those engineers who were contemplating linking-up the paper might act more as a deterrent than as a help. It cannot of course be too strongly stated that the linking-up of stations of the same frequency irrespective of voltage is an extremely simple matter. In Glasgow, as Mr. Lackie has said, we have done a lot in that connection. We started in [illegible] with St. Andrew's Cross and Port Dundas; in [illegible] Pinkston was added, and a few years ago we included Govan and Partick. In the ordinary way these stations are connected in ring. They may however form a closed system at times and even under these conditions we find power can be transferred without the use of any regulators on the interconnectors. There is no difficulty apart from the limits of the capacity of the various apparatus. I should like to ask the author whether he prefers the step-by-step regulators or regulators of the induction type, and if the latter what effect they are having upon the capacity of the interconnectors and the amount of wattless current involved. We have all kinds of plant running at varying speeds and the regulation varies very widely, but while an examination of the instruments on the switchboard shows that the better-regulating machines take up the fluctuations, with the very large number of plant units in commission the ammeters are fairly steady. When the author was describing the experiment at Salford he said there were voltage regulators at both ends, but he did not say that both voltage regulators were in operation. I should like to know if they were. I should also like to ask him whether it has been found feasible to work a combination of power stations with voltage regulators in each station. Obviously it would be of great assistance if that were feasible, because in the event of a short-circuit on the distribution network, each station would take its share of the extra power called for, whereas when running with only one voltage regulator the station with the regulator is doing far more than its share. Turning to the author's somewhat academic examples of how a load would come to be distributed, the estimates are of course all right in their way, but these are not the sort of things that happen in practice. The load is generally distributed in accordance with the steam pressure at the respective stations, and would also be governed by the breakdown to any part of the plant in any of the stations, or the load on the feeders. In Case (2), the impression given is that the desirable way of running stations in parallel is to make the load in ratio to the plant capacity and thus give each of the turbo-alternators its proportion. That is of course not really what is done. The turbo-alternators with the higher efficiency are given most of the work to do, whereas the older machines, which are put upon the busbars for safety reasons, have very little of the load given to them. The great success of working together in Glasgow has been partly due to the fact that it has made for economy by the lowering of the coal consumption, but more important still, the factor of safety has been greatly increased both upon the electric tramway system and upon the power and lighting system. On page 63, with reference to turbine regulation, the author points out that we must avoid having the smallest machine with the best regulation. We have had some experience of such conditions, but the machine in question does not seem to be adversely affected and only gets its fair share of the load. So far as earthed neutrals are concerned, we use method (*a*) described at the top of page [illegible], and that has been found to be satisfactory. I should like to ask the author what is the efficiency of phase converters? On the question of frequency changers I am glad that we in Glasgow have not required to consider this, as I think that the lot of the engineers who operate such plant is not to be envied. We all know that when there is a surge on the alternating-current system these frequency changers are bound to be unreliable. The output for which these frequency changers require to be designed is rather appalling. For instance, in the smallest station here which has a capacity of 30,000 kw., if we were linked up to other stations of different frequency we should apparently require frequency changers having a capacity of the order of 8,000 to 10,000 kw. I should like to sound one note of warning as to the size of interconnectors. We have found that when we link up two stations, one with variable load and the other a station on which the load is for power and lighting only, in addition to providing for the amount of power to be conveyed between the two stations, ample allowance must be made for the fact that the light and power station will be called upon to share, through the interconnector, the heavy fluctuations in load of the other station, and if only one cable is provided, these fluctuations have a great effect on the amount of power which can be passed between the two stations.

Mr. Seddon.

Mr. E. Seddon: Linking-up will no doubt hasten the growth of the larger stations, with a corresponding reduction of plant in the smaller ones, and I think there is little doubt that this change will operate to the advantage of the supply authorities concerned. Probably only in the case of stations with about equal plant capacity will exchange of load take place. At times transfer of load will have to be effected with low frequency and pressure down on the disabled station, so that auxiliary busbars will be required. The maintenance of a high power factor is necessary for the economical working of the generating plant and the transmission system, and in this respect, where frequency changers are necessary, I believe synchronous motor-generating plant is the best coupling to adopt. Substantial switchgear will have to be provided and fitted with overload instruments and possibly with reverse-current relays. Even when systems of similar frequency are coupled, I believe it will be found to pay to install synchronous condensers, which would be used at the consuming end of the line. I should like to mention that a very good paper on synchronous condensers by C. T. Mosman was published in the *General Electric Review* of July 1912 and is well worth reading. Where it is required to connect a single-phase station with a three-phase supply of a similar frequency, I believe the Scott-connected three-phase to two-phase transformers is the best method to use. This of course would necessitate splitting up the single-phase board into two sections. The single-phase station plant could then be used to balance phases or to take up peak loads when necessary.

Mr. Craig.

Mr. J. Hally Craig: I hope that in the course of his reply the author may have something to say with regard to

[illegible]

[illegible] to the frequency of the main system, should have their [illegible] that a special exciter is required for a rotary converter which must convert from continuous to alternating current wherever the frequency is not directly fixed by some other alternating-current machine.

Mr. Whysall is of the opinion that the commercial [illegible] ficulties. I think his opinion will not be dis- [illegible]

[illegible] rating conditions in Glasgow, and he also points [illegible] me of the precautions which must be taken under [illegible] whether the step-by-step regulator is preferable to the induction regulator. The step-by-step regulator is cheaper [illegible] ge curve it is in general [illegible] le wattless current from the [illegible] but this is not usually of importance on [illegible] relatively small capacity of the regulator. For automatic control an induction regulator is probably superior, and for very large capacities it may be preferable to the step-by-step type. At Salford the tests were made [illegible] rating stations. Whether it would be possible to operate [illegible] matter which would require trying out in practice. Mr. Page refers to my academic method of determining the distribution of load between the generating stations. I was quite aware that the engine governors were adjusted in the stations from time to time in order to distribute the load between the stations as desired, and I referred to this in the paper, but the cases I worked out referred to conditions where there was no time for hand adjustment, in other words for conditions [illegible] the load on the interconnector can be varied as desired. Mr. Page complains of the great size of the frequency changer which would be required for linking up stations the smallest of which has a capacity of 30,000 kw. It is probable that a 6,000-kw. frequency changer would be large enough to give satisfactory running on a system of this size, and it hardly seems likely that a much smaller set would have sufficient capacity to be of much use in equalizing the loads.

Mr. Seddon mentioned the use of the Scott-connected three-phase to two-phase transformer for connecting a three-phase to a single-phase system. This arrangement can be used where balanced loads can be maintained on the two-phase system of the transformer, but this is a condition which it is difficult to realize in practice and really requires that the single-phase system be changed to two-phase.

Mr. Craig asks whether the auto-synchronous machine is suitable. I assume that by the auto-synchronous machine he refers to what is usually called in this country a synchronous induction machine. This machine starts as an induction machine and automatically changes over to a synchronous machine. In order to obtain these desirable characteristics certain sacrifices must be made in the other qualities, and I believe that for frequency changers it will be found that the sacrifices which have to be made will more than outweigh any advantages likely to result from [illegible]

POST-WAR ELECTROTECHNICS.

ADDRESS TO THE STUDENTS' SECTION

By C. V. DRYSDALE, D.Sc., Member.

(*Address delivered* 14 *November*, 1916.)

Although we are passing through a time of anxiety and need for strenuous effort, I am glad to see that the Students' Section of our Institution is maintaining its energy. Our colleges and technical institutions have given freely of their best to the War, and the ranks of the Students' Section have been sadly depleted by those who have gone, some never to return. The Roll of Honour of the Institution includes many who have taken a prominent part in developing the Students' Section and in its discussions, and their loss will be severely felt.

But there is still new energy to be drawn upon from those who have recently entered the colleges, and there are also many whose work is recognized as far too important to allow of their being taken for the fighting ranks. Between them the standard of the Students' Section is being worthily upheld, and we may have confidence that as soon as the War is over it will more than regain its old vitality.

On the two previous occasions when I had the honour of giving this Address * I found it necessary to be somewhat depressing as to the prospects of the British electrical industry in general, and of the young technical graduate in particular. Subsequent experience has not altered my opinion, but the shock to our national self-satisfaction caused by the War may at last have given the stimulus necessary for us to set our house in order, and we may hope that the future of our technically-trained engineers will be much brighter.

When I first addressed this Section 10 years ago, I was actively engaged in technical education, and had been compelled to come to two depressing conclusions. The first was that the opportunity for doing good work in this direction was getting ever more restricted by the craze for centralization and control of teachers and the scope of their teaching. There seems to be a curse upon education in this country which leads to its control being in the hands of well-intentioned but incompetent cranks. The discussions on education in our parliament centre round two points, the question of religious instruction and the administration of funds; and as to whether the education provided is of real individual and national value no one seems to know or care. Even in educational circles themselves things are little better. A few years ago a justifiable cry arose for the recognition of technical subjects by the universities, and the B.Sc. degree in Engineering was heralded as a great reform. But the result was to set up a Faculty and Board of Studies in which a few competent teachers were diluted by some very indifferent busybodies, with the consequence that a syllabus was composed in which the questions of fundamental importance were swamped by masses of detail which made satisfactory teaching impossible. I have been asked to lecture on the skin effect in alternating-current traction systems to students who had never really mastered Ohm's law; and I have seen others instructed in the "best modern practice" in dynamo and alternator design who were certainly hazy as to the first principles of the magnetic circuit.

This sort of thing is typical of the tendency of modern education, and should be contrasted with the conditions of industrial life. A works manager, for example, is appointed by directors who are keenly concerned in the success of the work, and is then given wide powers to run things as he chooses, provided that he is successful. But teachers are appointed by education committees composed frequently of a few lawyers and representatives of local authorities, and are then expected to teach to some of these composite syllabuses for their students to pass examinations. Meanwhile the teacher is fettered with all sorts of rules and regulations, and if in spite of all discouragement he succeeds in developing a course of instruction which works satisfactorily, he may find it upset by the caprice of some central authority, who may even transfer his students to someone else for an essential part of the instruction. Not only does this system discourage the efficient teachers by making the work difficult, but it puts a direct premium upon incompetent self-seekers. In my experience I have seen the men who did the minimum amount of work to hold their posts, and spent their time in reading up for degrees and in lobbying for higher positions, going up steadily, while those whose devotion to their work led them to sacrifice all personal considerations to make it successful have been passed over by the educational authorities on the avowed plea that they were doing good work where they were. The number of really able instructors in scientific technology who both know their subject thoroughly and have a gift for teaching it is extremely small; their lives at best are very arduous, and unless conditions are made much more satisfactory for them in future, we are not likely to see good men attracted to teaching work. The whole of our primary, secondary, and technical education system needs drastic revision in the direction of emancipation of teachers from bureaucratic tutelage. "Get a good teacher and let him or her teach freely" is the only road to good education, and speaking personally I should like to see the whole of our State and municipal education swept away and its place taken by private or co-operative enterprise. The only test of efficient education is after-success, as Adam Smith so well contended, and neither university degrees nor college certificates can replace it.

This brings me to the second difficulty which has con-

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* *Electrician*, 1906, vol. 58, p. 259, and *Journal I.E.E.*, 1914, vol. 52, p. 286.

[illegible] Partly owing, no doubt, to the want of touch between our educational authorities and the various industries, and equally to the lamentable attitude which our manufacturers have until quite recently taken towards scientific training, the prospects were, to say the least, poor, at any rate in this country. That the best of our technically-trained men can vie with the best in the world is undoubtedly true, and [illegible] United States, but in England many of them have been eating out their souls with poor opportunities, poor remuneration, [illegible] A few months ago an American official of high standing in technical work expressed his astonishment to me at the utter waste of youthful ability in this country. "You have some of the finest young talent in the world," he said, "and you make no use of it, you give it no chance." It is painfully true. Our higher positions are for the greater part filled by pompous incompetents who are afraid to display their ignorance before capable people, and who feel that they can only maintain their dignity by industriously snubbing any signs of capacity.

When in charge of the laboratory arrangements at the Northampton Polytechnic Institute, I naturally considered what was the most useful training which could be given in such laboratories, and I came to the conclusion that to develop the testing of electrical plant so that our trained men would be able quickly and thoroughly to test generators, motors, and transformers of every type and to analyse their losses completely so as to check their design and to give indications as to the possibility of improving them, ought to be of the greatest value to the manufacturer and consumer. But what did we find? Simply that manufacturers were not interested in the goodness or badness of their machines, but only in selling them. If a young fellow was prepared to make use of his technical knowledge for the purpose of deluding inquiring engineers into the belief that the machines of his firm were the best in the world, there was a welcome and a fair salary ready for him, but for the man who wanted to do good work in [illegible] really the best in the world there was a discouraging reception. There does not seem at present to be a single satisfactory British single-phase motor on the market, or any prospect of one on the lines on which our manufacturers have been working.

I soon came to the conclusion that to educate students [illegible] conviction of the futility of modern educational administration, determined me to retire from teaching work in favour [illegible]

The Lesson of the War.

[illegible]

technically-trained student into his own legitimate sphere. Even those of us who had a fairly good idea of the advances which Germany has been making in technical directions were startled to discover, a few months after the outbreak of war, the extent to which we had become dependent upon her for some of the most important materials and instruments of production. In every branch of mechanical and electrical engineering German tools and materials played an important part; our largest supply stations were equipped with German plant; and many of our manufacturers were making machines assembled from German parts. There is probably hardly a factory in England which was not to some extent paralysed by the inability to obtain material which it had been getting from Germany, and if the War had been delayed a few years we should probably have been still worse off. It is little wonder that the Germans had become imbued with the idea that Britain was decadent, and that they had a right to the domination of the world for their superior efficiency. In the long run efficiency must tell, and if Germany had not been too eager and struck too soon, it is quite possible that she would have gained the day, from our sheer inability to stand alone, and from her domination of our industries. Fortunately, she did strike too soon, and fortunately the splendid individuality and adaptability of our young engineers enabled us rapidly to retrieve our position, so that to-day we see munition works of vast magnitude in full swing, with hosts of capable young engineers managing them; and it is quite safe to say that Germany will find a very different England to compete with when the War is over. And the lesson which has been driven into our lawyer politicians and generals is that this is a war of engineering, where every powerful and delicate device which the resources of science can give us is needed. Every form of energy has been employed for transport, explosives, and signalling, and one of the most fascinating chapters in technical science will be written after the War, when the marvellous devices it has brought forth may be described. But only those who have been concerned in their production can know how much this development has been hampered by the want of material which we ought to have had available, and which the Germans had ready to their hands.

It has been said that a Briton is at his best when his back is against the wall, and the way in which some of our manufacturers have risen to the emergency is certainly splendid. The War has galvanized them into life, and it is a fact testified to even by the American critic above mentioned, that it has made it possible to get things done, even unconnected with the War, much more promptly than in peace time. And one cannot help feeling sanguine that the lesson so sharply given us by the War will endure, and that our efficiency as a manufacturing nation will be permanently raised. For this reason I hope that the day of the technically-trained engineer is dawning, and that before many years are over we may have some of the opportunities which his more fortunate German and especially American contemporaries have been enjoying. When we see what American factories have been doing in equipping large research laboratories, manning them with [illegible] which compare favourably with the proceedings of our scientific societies, we can only wonder what blight has fallen upon us and hope that the War will have given us that awakening which our King proclaimed the need for years ago.

We have still one great asset in this country—the reputation for honesty and reliability, which Germany with all her scientific ability has not been able to secure, in certain directions at least. All the more possible should it be for us to regain supremacy if we will adopt scientific methods.

The Opportunities for Development.

When we come to consider the direction in which progress is to be made, there is still certainly a great opportunity for the improvement of British electrical machinery, especially as regards single-phase and polyphase motors and their application to traction and industrial work. There is no need to dwell on this, and we may expect to see considerable progress before long. But it will only be effected by bringing a scientific spirit to the work, the determination to make considerable present sacrifices for future results, and to analyse the defects and sources of loss in each type of machine with a view to steady improvement. This is the work we set ourselves at the Northampton Institute years ago, and the justice of this view has been emphasized by the recent presidential address of Mr. Gerald Stoney to the Engineering Section of the British Association, in which he pointed out that the steady development of the steam turbine from its scientific toy stage to the immense engines of to-day has been due to the constant testing and analysis of losses.

This brings me to the second branch of the industry, which offers great opportunities—that of electrical measuring instruments. Although this has always been a favourite subject of mine, and was recommended to your notice in my earlier addresses, I must confess that it was not until the last few months, during which Mr. A. C. Jolley and I have been at work on a book concerning it, that I realized what a field it offered. We have had numerous treatises dealing with dynamo design in all its details, but the design of electrical instruments is almost an untouched field, and the opportunities still available for new and improved designs as regards British instruments are considerable. In connection with this work we have had occasion to take to pieces and examine the construction of a number of British, French, German, and American instruments, and anyone who has done so will see how much needs to be done. We have now found it possible to reduce the design of several types of instruments to a fairly definite shape, and the comparison of many of the instruments on the market with such a design is most instructive. Even in such matters as standard resistances for current measurement, which have become almost a German preserve, I have found opportunity for material improvement, and I am convinced that if we choose to tackle the matter seriously, we can beat the Germans even in this sphere in which they have made wonderful progress. There is still room for good indicating instruments and standards for alternating-current supply, especially in those suitable for wireless work, for well-designed equipments for supply-meter testing, and for devices for mechanical measurements.

Another great field for new development is, as I also emphasized on a previous occasion, that of telegraphy and telephony. Nothing in the history of electrotechnical science has been so remarkable as the development of electrical signalling. Just as finality appears to be reached in a certain direction, a new possibility opens up; and telegraphy, which is the oldest of the electrotechnical applications, is to-day the youngest and most progressive of them. Thanks probably to our insular position and great commerce, this is a field in which we may legitimately be proud of our record. But the recent work of Colonel Squier, and others, shows there is yet a prospect of a revolution in cable telegraphy, and there is no better scope for an original enthusiast than in either cable or wireless signalling.

Then again there is the question of materials, of good alloys for resistance work and for springs, of satisfactory mechanical insulators, of strong and light materials for aeronautical work, as well as optical media, etc. Up to the present German manufacturers have had a great advantage over our own in this respect, but there is reason to hope that this will be rectified soon. For example, Messrs. Wiggins have turned their attention to resistance alloys, with the result of producing some which in quality and cost compare most favourably with the German products.

Last, but not least, there is the electrochemical industry, and above all the electrical production of nitrates, upon which I ventured to lay great stress when I last addressed you. The War has enormously increased the importance of this matter both for the production of fertilizers and of explosives, and it is pretty safe to say that Germany would have collapsed many months ago but for her remarkable achievements in this direction. The need for development in this direction in this country is most urgent, and a start has already been made, although I do not know how much has yet been effected. In view of the outcry for home-grown food (which is usually sublimely unconscious of the importance of fertilizers) the importance of this matter, and of the catalytic processes which the Germans have devised for the conversion of nitrates into ammonia, etc., cannot be over emphasized.

The Industrial Outlook.

The darkest cloud on our horizon is, however, the industrial problem. Of late years the neglect of fundamental economic studies, about which I ventured to give a most serious warning in my first Address to this Section, has been bearing fruit at a most alarming rate, and I make no apology for introducing the matter again. In fact, the problem is so serious that our technical papers have been obliged lately to devote considerable attention to the prospects of industry after the War. But it is rare to see the matter treated from its fundamental aspects. The root of the mischief is the Socialistic fallacy that there would be plenty for all if it were only properly distributed, and that the wage earners are constantly exploited so as to receive only a fraction of the value of their labour. These ideas have been so sedulously propagated by the Socialists and trade-union leaders, so weakly combated by employers, and so constantly pandered to by the Government and by the sentimental public, that the whole attitude of organized labour has become a menace to the community. No one can be keener than myself to see the wages of the working classes rising rapidly and continuously, but it must be by increasing the efficiency and demand for their services, and by the encouragement of individual initiative and capability. Unfortunately, instead of keeping to the good [illegible] of free trade, instead of letting the best men rise through their own prowess and exertions and of letting wages and prices be settled by free competition and individual bargaining, the cry has been continually for State regulation of wages and of the cost of living. Worse still, the utter misconception of the true facts of existence [illegible] that the struggle is between labour and capital, instead of between mankind and the niggardliness of Nature, and the belief that we are actually suffering from over-production, have led the working classes into the preposterous and suicidal notion that they are best serving the interests of their class by strikes and by limitation of output. What this country has lost in commerce before the War, as well as the lives that have been thrown away through insufficiency of munitions since the War began, due to this criminal folly, makes one sick to think of. Men, working diligently at important munition work, have been stopped by their companions and told that they must not turn out more than one-third of the work they were easily capable of doing. Others have been systematically losing time by day in order to work at night and on Sundays to get higher overtime rates. Idling and shirking have been rife. And the War has only brought into relief tendencies which were steadily undermining our industries in peace. How could we expect to keep pace with the well-trained and steadily working German mechanics, directed by their highly skilled foremen and scientific engineers? If the same conditions are to prevail after the War, it will not be worth the winning. The ultimate fate of our Empire will be as certain as if Germany had destroyed our fleet.

I am far from laying the whole blame for this condition of affairs on the wage earners. It is shared by the whole community in our utter failure to put economic facts before the masses, and to counteract the Socialist teaching. If you listen to Socialist orators in the parks or at street corners, you are almost certain to hear before long that the "workers" are "exploited" by the employers to the extent of getting only a fraction of the value of their labour, while the employer is supposed to take the rest. Now it is perfectly true in many industries—the electrical industry for one—that the amount paid in wages to the man who makes a certain machine or instrument is only about one-fourth or even less of its list price. But for every pound given to a man in wages, he commonly uses about a pound's worth of materials—he uses buildings, tools and machinery, power and light, he needs drawings, patterns, and templets, the supervision of a foreman, etc., which may easily amount to another pound. And then come the administrative charges, clerks and book-keepers, stationery, postage, packing, price lists, patents, discounts, and last—and often least—profits. We thus have the rough classification:—

Mechanics' wages	one-fourth	price of goods
Materials	one-fourth	
Factory expenses...	one-fourth	
Administrative expenses, discounts, and profits	one-fourth	

It will be seen at a glance that the proportion paid as mechanics' wages is not in the least unreasonable, and that the bulk of the remainder is also paid in wages to the producers and distributors of material, to the foremen, toolmakers, draughtsmen, clerks, etc. In fact in the bulk of good-class work there is practically no margin of profit at all if the mechanic's wages exceed one-quarter of the price. The fallacy in the worker's mind is that he imagines he is the only producer, because he shapes the parts and assembles them to form the machine, losing sight of the large number of other workers necessary to make his processes effective.

All this is absurdly elementary, but where will you find a clear grasp of it in popular or other writings on social subjects? And where will you find it realized that labour in itself is of no value whatever? As technical students you know the distinction between force and work. Suppose you have a heavy load to be held in position while being fixed. You know that after it has once been lifted no energy is expended in keeping it up. One workman will support the load on his shoulders for hours, grumbling all the while about this hard "work," while another will get hold of a few bits of wood and shore up the load in a few minutes, and go off to do really useful work elsewhere. Is the first man to be paid a "living wage" for his exhausting but useless feat? Again, power, as such, can be produced by combustion engines at a fraction of a penny per horse-power-hour. Even, therefore, if a man works hard and steadily at the rate of one-tenth of a horse-power, his mechanical energy as such is not worth a farthing an hour. It is his skill and intelligence that really count, and these differ to an enormous extent, showing the absolute fallacy of a standard wage, or of the Marxian doctrine of labour values. However hard a man may work, unless his skill is such as directly or indirectly to increase the necessaries of life by as much as he consumes, he is not entitled even to a living wage. Nature knows no living wage. The man who is wrecked on a desert island may labour unceasingly and yet starve, or, if he has the ability, may do comparatively little and yet obtain large "excess profits." It is the forces of Nature which "work"; our business is to get them to operate to our advantage, and our success or failure must rightly depend upon our ability to do this.

The absurdity of regulation of wages can be shown in a very simple manner. If I have a knife in my pocket which I am willing to dispose of, I can ask anyone what he will give me for it, and we can settle the bargain in a minute between ourselves. Who has a right to interfere? But suppose that I have made the knife myself, taking several days to do so for want of skill and facilities, and that I sell it for a shilling. What is my wage? If it is permissible to make a free bargain between individuals for an article which is the product of labour, it cannot be wrong to make a bargain in the labour which produces it. Only by free bargaining in commodities can the true value to the community be fixed, and only by free bargaining in labour or services can their true value to the community be arrived at.

Supposing that I want some work done suitable for a boy or girl, and offer 10 shillings a week wages, but that a man with a wife and family comes to me and says "I can't get anything better, let me have the place." Am I wrong in giving it him, and am I responsible for his family affairs? There is something seriously wrong somewhere in a full-grown man wanting to work for 10 shillings a week, but the responsibility is no more the employer's than it is that of any other member of the community. For many years

I have abandoned practically all other interests to study proposed remedies against low wages, and I firmly believe that in many cases it pays an employer to offer high wages in order to get good men, but I absolutely deny the right of any organized body or State to interfere in a free bargain between man and man for the exchange of goods or services. A small shopkeeper who is unskilful in producing or obtaining at reasonable prices goods which the public requires may see his business go down to the starvation point, yet no one in his senses would suggest that the public should be compelled to buy from him or to offer a high price for his goods. Equally absurd is to fix a standard price for labour. The only result is to eliminate effort, to discourage ability, to set up false values, to cloak real economic issues, and to substitute political agitation for efficiency. The only legitimate method of increasing wages is in increasing efficiency, i.e. increasing the value of the individual to the community. If that is done, free competition and individual bargaining will make wages rise independently of any organization.

All this may sound very harsh, although it is intended in the most humanitarian spirit, and it is certainly in direct conflict with the general trend of opinion at present. But many of you will in time have to bring all your forces to bear in tackling industrial problems, and it is to technically-trained engineers, with their constant confronting of practical problems, not to academic economists or time-serving politicians, that I look for their solution. From the day the War ends, the industrial and economic questions will become urgent, and the future of our country and Empire depends upon how they are handled. Our help must come from our great British pioneers, whom we have so shamefully neglected—Adam Smith, Mill, Chalmers, Bentham, Darwin, Huxley, and Herbert Spencer, in the revival of enlightened individualism, and in the resolute determination to depend on our own efforts and on voluntary co-operation, repelling as much as possible the benumbing influences of State control and enforced organization.* In any case, I feel confident that the prospects before the Students' Section are brighter than at any previous time in its history, and I sincerely hope that it will take a great part in restoring the uccess of British engineering.

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* It may appear at first sight totally inconsistent for me to object so strongly to State interference with education and industry, and at the same time to pay such a tribute to the efficiency of Germany, where centralization has been carried to the highest pitch. But it is democratic centralization by representatives or committees which is and must be inefficient. Autocratic centralization is frequently most highly efficient. Its evil is its infringement of liberty, and the scope it gives to overweening ambition, as shown in this War.

PROCEEDINGS OF THE INSTITUTION

[illegible] ORDINARY MEETING, 14 DECEMBER 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on the [illegible] November, 1916, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

The PRESIDENT announced that a greetings card in the name of the Institution would be sent early the following week to all members on active service.

A paper by Mr. R. W. Weightman, Member, entitled "Colonial Telegraphs and Telephones" (see page 91), was read and discussed, and the meeting adjourned at 10.5 p.m.

[illegible] ORDINARY MEETING, 11 JANUARY 1917.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on the 14th December, 1916, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Messrs. H. S. Thompson and I. H. Jenkins were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Associate Members.

Bellman, Harold, Corporal, [illegible]
Clunas, James Wilson S.
Cottam, Harry Leslie.
Darling, William Noble.
Dixon, William.
Drury, James Denver.
[illegible]
[illegible]
[illegible]
Hayhurst, Harry Holman.
Hilton, John George M.
Hobson, William Falshaw.
Hughes, Arnold Alexander.
Lincoln, John William, Capt., R.E.
McDougall, Alfred.
Mason, Frank.
Piggott, James William.
Spence, James.
Sutton, Charles Cecil.
White, Joseph.
[illegible]

Graduates.

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
Glass, Charles George.
[illegible], Sapper 2922, L.E.E.
[illegible]
Mortimer, Matthew Johnson.
Newman, Arthur Sidney.
[illegible]
Stephenson, Cyril Heath.
Strand, Ralph Rixon.

Students.

[illegible]
Bromley, James Treasure.
Carlisle, Ralph Sydney.
Cooper, Harold Ritter.
Cousins, Cyril George.
de Melho-Vilhena, Themistocles.
Everett, Arthur George.
Farrington, George Howard.
Gibbard, Henry England.
Hall, William Noel, Sapper, L.E.E.
Harmsworth, Harry Brooke.
Lisle, George Stanley.
Mann, Herbert Clarence.
Miller, John Ashbridge.
Nott, Madeline (Miss).
Paddon, Errol Graham E.
Robinson, Geoffrey.
Thornton, Norman.
Travers, Archibald.
Tunnah, Albert Edward.
Yung, Chi Wei.
Zannoni-Chauvet, Costanzo.

TRANSFERS.

Associate Member to Member.

Chamen, Charles Henry K.
Chapman, Fitzroy Tozer, D.Sc.
Eaton, George Herbert.
Monkhouse, Samuel Ernest, Capt., R.E.
Morgan, Thomas Bernard.
Smith, Tom Vincent.
Whatnall, James Alfred.

Associate to Member.

Cochrane, Ernest James.
Watlington, Victor.

Graduate to Associate Member.

Alexander, John Wallace.
Bairsto, George Edward, D.Sc., B.Eng.
Bond, Harold.
Brodie, William.
Burnett, Francis Edgar.
Coleman, Herbert Stoddard.
Dainty, William Reginald, Flight Sub-Lieut., R.N.
Day, Isaac.
Fairfield, Thomas James.
Lloyd, John Ambrose.

Student to Associate Member.

Blakemore, Ernest.
Bottone, Reginald Amadeus R.
Bramwell, Henry Percy.
Driver, Edgar Thomas, B.Sc.
Dudley, Roderick World.
Hornyold, Henry.
Leeson, Bruce Hamer.

Student to Associate Member—continued.

Linstow, Frederick Norman.
McCall, George William.
Marquand, Hilary Strina.
Marshall, Claude Roland.
Mathieson, Donald.
Morris, Alfred.
Rowcliffe, Frederick.
Sizer, Nelson.
Tipping, George Owen, Lieut., R.E.
Topham, Frank Charles.
Webb, Estlin Horrox.

Student to Graduate.

Arnold, Arthur.
Jackson, Peter.
Johnston, Ernest Clifford.
Kalé, Purushottam Balkrishna, B.Sc.
Mistry, Nusserwanji Ruttonji, B.A., B.Sc.
Paddock, William George.
Stell, Norman.
Warden, Hirjibhoy Byramji.

The PRESIDENT: At our last meeting I mentioned that it had been decided to send to members on active service a Christmas card from the President, Council, and members of the Institution. We have received a number of acknowledgments. The most interesting is from Major Battye, who has sent us a metal tablet from the Somme, which members will have an opportunity of examining after the meeting. The Council propose to have it framed and hung up with a notice stating that it was presented by Major Battye as a memento from Contalmaison.

A paper by Messrs. F. Gill and W. W. Cook, Members, entitled "Principles involved in Computing the Depreciation of Plant" (see page 137), was read and discussed, and the meeting adjourned at 9.50 p.m.

INSTITUTION NOTES.

ROLL OF HONOUR.

(FIFTH LIST.*)

Killed in Action.

Mahon, Private A. T.	London Regt.	Student
Murray, Actg. Sergt. J. H., D.S.M.	Divisional Engineers, R.N.D.	Associate Member
Stafford, Lance-Corpl. R.	Machine Gun Corps	Student
Wilson, 2nd Lieut. T. P.	Bedfordshire Regt.	Student

Died of Wounds.

Burrage, 2nd Corpl. C. J.	Royal Engineers	Student
Dutch, 2nd Lieut. E. J.	Royal Fusiliers	Associate Member

MILITARY HONOURS AWARDED.

(FIFTH LIST.†)

G.C.B.

Jackson, Admiral Sir H. B., K.C.B., K.C.V.O.	Royal Navy	Member

C M G

Cormack, Lieut.-Col. J. D.	General List	Member
Hopkinson, Major B.	Unattached List, T.F.	Member
Ruck, Major-Gen R. M., C.B.	Reserve of Officers	Member

Distinguished Service Order.

Evans, Major L.	Royal Engineers	Associate Member
Harrison, Major N.	South African Engineers	Associate Member
Lintott, Major A. L.	London Regt.	Graduate

Military Cross.

Beamish, 2nd Lieut. F. N. H.	Royal Warwickshire Regt.	Graduate

"He commanded two companies and reorganized them, consolidated and held the position under intense fire. He has previously done very fine work."—*London Gazette*, 11 December, 1916.

Bowers, Lieutenant E. G.	Northumberland Fusiliers	Graduate
Cardew, 2nd Lieut. J. H.	Royal Field Artillery	Associate Member
Carty, Captain S. W.	Army Service Corps	Associate Member
Jackson, 2nd Lieut. H. Y. V.	Royal Engineers	Student
Long, Lieutenant R. F.	Royal Field Artillery	Associate Member
Marx, Captain R.	Royal Field Artillery	Student
Pope, Lieutenant W. G. T.	Royal Engineers	Associate Member
Suggate, Captain C. F. D.	Army Ordnance Dept.	Associate Member

Order of the Nile (Fourth Class).

Robinson, Commander E. G., V.C.	Royal Navy	Associate Member

Mentioned in Despatches.

Alexander, Major R. D. T.	London Regt.	Associate Member
Barker, Major J. S., M.V.O.	Royal Engineers	Associate Member
Battye, Bt. Major B. C., D.S.O.	Royal Engineers	Associate Member
Bennett, 2nd Lieut. E. J. L.	Royal Field Artillery	Associate Member
Bumpus, 2nd Lieut. B. E.	Northumberland Fusiliers	Associate Member
Collins, Captain D. S., D.S.O.	Royal Engineers	Associate Member

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* See vol. 54, pp. 64, 447, and 674, and vol. 55, p. 55.
† See vol. 54, pp. 306, 518, and 674, and vol. 55, p. 56.

[illegible], Major [illegible] B. D.	Royal Engineers	Member
[illegible], Lieutenant [illegible] J. G.	General List	Member
[illegible], Major S. H., D.S.O.	Royal Engineers	Associate Member
[illegible], Captain A. [illegible], D.S.O.	Royal Engineers	Associate Member
[illegible], Major J. H.	[illegible]	Member
[illegible], Lieutenant P.	Royal Engineers	Associate Member
[illegible], Captain [illegible] H. W.	Royal Engineers	Associate Member
Ethelston, Lieutenant S.	Royal Field Artillery	Student
Evans, Major L.	Royal Engineers	Associate Member
[illegible], Captain S. E.	Royal Engineers	Member
[illegible], Major C. C. A.	Royal Engineers	Associate Member
Hopkinson, Major B.	Unattached List, T.F.	Member
Hunt, 2nd Lieut. T. C.	Royal Engineers	Associate Member
Hunter, Captain E. B.	Royal Engineers	Associate Member
[illegible], Major F. A.	Royal Engineers	Associate Member
Jacques, 2nd Lieut. G.	Royal Flying Corps	Associate Member
[illegible], Captain H. M.	Army Ordnance Dept.	Associate Member
[illegible], Captain A. H.	Royal Field Artillery	Member
[illegible], Major H. P. T., M.C.	Royal Engineers	Associate Member
[illegible], Major A. J.	London Regt.	Graduate
[illegible], Major R. A.	Royal Artillery	Associate
[illegible], Lieut.-Col. A. G. L.	Canadian Field Artillery	Associate Member
Maguire, 2nd Lieut C. E.	Royal Engineers	Associate Member
Mann, Lieutenant [illegible]	Royal Engineers	Associate Member
[illegible], Lieutenant G. S.	Royal Engineers	Associate Member
Milliken, Captain [illegible]	Royal Engineers	Associate Member
Minshall, Major T. H.	Royal Engineers	Member
[illegible], 2nd Lieut. C.	Royal Engineers	Associate Member
[illegible], Captain H.	Royal Engineers	Member
[illegible], Commander E. G., [illegible]	Royal Navy	Associate Member
[illegible], [illegible] T. A.	Royal Engineers	Associate Member
[illegible]	[illegible]	Member
[illegible], Captain [illegible]	Army Ordnance Dept.	Associate
Short, Captain E. A.	Staff for R.E. Services	Associate Member
Simpson, Major L. S.	Royal Engineers	Associate
Smyth, Lieutenant A. H.	Army Ordnance Dept.	Associate Member
Sparks, Captain H. C., D.S.O., M.C.	London Regt.	Member
[illegible], Captain R. E.	Royal Engineers	Associate Member
Stanley, Major R.	Royal Engineers	Member
Timmis, Captain F. W.	Royal Garrison Artillery	Associate Member
Trippe, Lieutenant C. F.	Royal Engineers	Associate Member
Tucker, 2nd Lieut. W. S.	General List	Associate
Tuppen, Captain H. R.	Army Service Corps	Student
Wayne-Morgan, Major J., M.C.	Royal Engineers	Member

MEMBERS ON MILITARY SERVICE

(TENTH LIST.*)

MEMBERS.

Name.	Corps, etc.	Rank, etc.
Dixon, H. L.	Royal Flying Corps	2nd Lieut.
St. John, E. C.	R.N.V.R.	Lieutenant
Webb, H. L.	General Staff	Captain
Williams, A.	R.N.V.R.	Lieutenant

ASSOCIATE MEMBERS.

[illegible], H.	Royal Engineers	2nd Lieut.
Baker, J. A.	Army Service Corps	Lieutenant
[illegible], H. F.	Royal Marines	Sergt.-Major
[illegible], H.	Royal Engineers	Corporal
Bodkin, G. S.	Royal Engineers	2nd Lieut.
Bridger, T. W.	Australian Flying Corps	
Brotherton, C. E.	Royal Engineers	2nd Lieut.
Buckley, P.	Royal Engineers	Captain
Corbett, R. W. T.	Royal Engineers	2nd Lieut.
Curteis, A. F. R.	R.N.V.R.	Lieutenant
Dixon, W.	Royal Engineers	2nd Lieut.
Drury, J. D.	Royal Engineers	Cadet
Duggan, J. P.	Royal Australian Navy	Elec. Draughtsman
Elkins, C. A. I.	Royal Engineers	Sapper
Fraser, D. M.	Royal Engineers	Corporal
Gillespie, W.	Royal Engineers	Lieutenant
Hayhurst, H. H.	New Zealand Machine Gun Corps	Lieutenant
[illegible], D. H.	Military Aeronautics Directorate	Captain
[illegible], H. G.	Royal Flying Corps	Lieutenant
Lincoln, J. W.	Royal Engineers	Captain
Loftus, J. J.	Attached Royal Engineers	Lieutenant
Lyons, H. M.	R.N.V.R.	Sub-Lieut.
McDougall, A.	Royal Engineers	2nd Lieut.
Madsen, J. P. V.	[illegible] Engineers	Lieutenant
Meaby, J. W. G.	Royal Engineers	2nd Lieut.

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* [illegible]

Associate Members—*continued.*

Name.	*Corps, etc.*	*Rank.*
Murray, G.	Indian Army Reserve of Officers	2nd Lieut.
Murray, J. C.	Royal Flying Corps	2nd Lieut.
Pallott, C. F.	Royal Naval Air Service	Sub-Lieut.
Palmer, J.	Canadian Infantry	Lieutenant
Pollett, E. H.	R.N.V.R.	Sub-Lieut.
Record, O. L.	Royal Engineers	Sapper
Rorke, A.	Royal Engineers	Lieutenant
Smith, J. R.	New Zealand Forces	Captain
Spence, J.	Royal Engineers	2nd Lieut.
Trickett, A. L.	Royal Engineers	Sapper
White, J.	Australian Imperial Force	Staff-Sergt.
Wilson, G. S.	Inns of Court O.T.C.	Private
Wilson, J. C.	Royal Engineers	Sapper
Wythes, F. V.	Royal Engineers	2nd Lieut.

Associate.

Chalkley, A. P.	British Red Cross	Engineer

Graduates.

Arnold, A.	Royal Navy	Eng. Sub-Lieut.
Bailey, C. F.	Royal Engineers	Sapper
Bourne, G.	Royal Engineers	Sapper
Carter, F.	Army Service Corps	Private
Chalmers, W. D.	Royal Engineers	Sapper
Cooke, L. E.	Australian Engineers	Lieutenant
Glass, C. G.	Machine Gun Corps	2nd Lieut.
Hodges, E. S.	Royal Engineers	Sapper
Jackson, S. N.	R.N.V.R.	Chief Petty Officer
MacIndoe, G.	New Zealand Signal Section	Private
Newman, A. S.	Royal Engineers	Lance-Corpl.
Smith, A. E.	Royal Engineers	Captain
Strand, R. R.	Royal Engineers	Staff-Sergt. Mechanist

Students.

Ball, W. J. E.	Royal Navy	
Ballard, C. M.	Royal Engineers	2nd Lieut.
Bromley, J. T.	Royal Engineers	Lance-Corpl.
Carlisle, R. S.	Royal Engineers	Sapper
Clegg, P.	Royal Naval Air Service	1st-class Air Mechanic
Cowen, J. S. M.	Army Service Corps	Private
Gibbard, H. E.	Royal Engineers	Lance-Corpl.
Giller, W. L.	Canadian Engineers	Sapper
Goodwin, J. J.	Machine Gun Corps	Gunner
Gordon-Campbell, W. F.	Royal Engineers	Lance-Corpl.
Hall, W. N.	Royal Engineers	Sapper
Jepson, C.	Royal Naval Air Service	Air Mechanic
Levy, I.	Army Service Corps	Mechanic
Marshall, C. R.	Royal Engineers	2nd Lieut.
Miller, J. A.	Highland Light Infantry	2nd Lieut.
Morton, C. A.	Royal Flying Corps	2nd-class Air Mechanic
Radley, W. G.	Royal Engineers	Sapper
Riley, T. S.	Army Service Corps	Private
Ryder, P. G.	Army Service Corps	2nd Lieut.
Storey, C. E.	Royal Fleet Auxiliaries	Electrician
Thornton, C. V.	Royal Flying Corps	2nd Lieut.
Travers, A.	Royal Flying Corps	2nd Lieut.
Wilson, S. K.	Royal Engineers	Sapper
Young, S.	Canadian Engineers	Sapper

PROMOTIONS, TRANSFERS, ETC., OF MEMBERS ON MILITARY SERVICE.

(SIXTH LIST.[*])

Members.

Name.	*Corps, etc.*	*Rank.*
Beckett, A. J.	Royal Engineers	Captain
Clarke, J.	Royal Engineers	2nd Lieut.
Dashwood, E. S.	Royal Marines	Lieutenant
Day, B. J.	Royal Engineers	Captain
Hammond, R. W.	Training Reserve	Captain
Stanley, R.	Royal Engineers	Major
Thorne, G. S.	Royal Flying Corps	Captain

Associate Members.

Amberton, R.	General List	Captain
Anderson, A. M.	Royal Engineers	Lieutenant
Binyon, B.	Royal Naval Air Service	Flight Com.
Blair, F.	Royal Engineers	Lieutenant
Bollam, C.	Royal Engineers	Lieutenant
Bond, H.	Royal Garrison Artillery	Lieutenant
Brazier, C. C. H.	Indian Army Reserve of Officers	2nd Lieut.
Briggs, J. C.	Royal Flying Corps	Captain
Caparn, E. T.	Royal Engineers	Lieutenant
Carden, E. D.	Royal Engineers	Major
Cardew, J. H.	Royal Field Artillery	Actg. Capt.
Collins, D. S., D.S.O.	Royal Engineers	Major
Danson, J. R.	Cheshire Regt.	Lieutenant
Davidson, A. E., D.S.O.	Royal Engineers	Lieut.-Col.
Davidson, C. H.	Royal Field Artillery	Sergeant
Dobell, H.	R.N.V.R.	Lieut. Com.
Eadie, J. C.	Royal Navy	Eng. Lieut.
Emmott, H.	Royal Engineers	2nd Lieut.
Fendick, A. C.	Royal Garrison Artillery	Lieutenant
Fidoe, J. W.	Royal Engineers	2nd Lieut.
Green, Harry	Royal Engineers	2nd Lieut.
Hamilton, F. T.	Royal Engineers	Lieutenant
Hardie, C. C. A.	Royal Engineers	Major
Hilder, W. T.	Royal Engineers	2nd Corpl.
Hindle, J. N.	Royal Engineers	Lance-Corpl.
Hipwell, L. W.	Royal West Surrey Regt.	Captain
Hogarth, L. B.	Royal Engineers	Captain
Holroyd, H. C.	Royal Engineers	Lieutenant
Huddart, A. H.	Army Service Corps	Major
Hutt, A.	General List	Captain
Jones, J. G.	Royal Fusiliers	Lieutenant
Joseph, H.	Royal Engineers	Lieutenant
Kapp, R. O.	London Regt.	Private
Keelan, R. E., M.C.	Royal Engineers	Actg. Capt.
Kefford, H. W.	Royal Garrison Artillery	2nd Lieut.
Kerridge, D.	Royal Engineers	2nd Lieut.
Kirkpatrick, W. D.	R.N.V.R.	Lieutenant
Langford, T. H.	Royal Engineers	2nd Lieut.
Leeson, B. H.	Royal Engineers	2nd Lieut.
McCallum, A. H. S.	Royal Flying Corps	Captain
McDougall, J. K.	Australian Engineers	Cadet
McNaughton, A. G. L.	Canadian Field Artillery	Lieut.-Col.
Masters, F. H.	Royal Engineers	Captain
Moberly, R. M.	Royal Engineers	Lieutenant

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[*] See vol. 54, pp. 307, 404, 579, and 675, and vol. 55, p. 59.

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	Royal Flying Corps	Captain
[illegible]	[illegible] R.N.A.S.	Lieutenant
[illegible]	[illegible]	Lieut.-Col.
[illegible]	Royal Engineers	Sergt.-Maj.
[illegible]	Royal Engineers	Captain
[illegible]	Army Service Corps	Captain
Powell, C.	Royal Engineers	Actg. Capt.
[illegible]	Royal Engineers	Major
[illegible]	Royal Engineers	Captain
Roseveare, L.	Royal Garrison Artillery	Captain
[illegible]	Royal Engineers	Captain
Sim, N. S.	[illegible] Highlanders	2nd Lieut.
[illegible]	Royal Engineers	Lieutenant
[illegible]	Royal Engineers	Major
[illegible]	Royal Engineers	Captain
Taylor, H. B.	[illegible]	[illegible]
[illegible]	R.N.V.R.	Lieutenant
[illegible]	Royal Engineers	Lieutenant
Vitty, T. H.	Royal Flying Corps	Captain
[illegible] E. H. E., M.C.	Royal Engineers	Lieutenant
[illegible]	Royal Garrison Artillery	Captain

[illegible]

[illegible]	Royal Engineers	2nd Lieut.
[illegible]	Royal Garrison Artillery	2nd Lieut.
[illegible]	Royal Field Artillery	Captain
[illegible]	Royal Engineers	Lieutenant

[illegible]

Aspinall, G. D.	Royal Engineers	Captain
[illegible]	Royal Engineers	Lieutenant
[illegible]	[illegible]	Captain
[illegible], M.C.	Royal Engineers	Lieutenant
[illegible]	Royal Engineers	[illegible]
[illegible]	[illegible]	[illegible]

STUDENTS

[illegible]	[illegible]	*Rank*
Benning, B. S.	Royal Naval Air Service	Flight Com.
Binnie, R. D.	Royal Marine Artillery	Lieutenant
Broadwood, L. A. T.	Royal Engineers	Lieutenant
Burford, W. B.	Royal Engineers	Actg. Capt.
Cam, A. N.	Royal Engineers	2nd Lieut.
[illegible] D. S.	Royal Garrison Artillery	2nd Lieut.
Collyer, G.	Royal Engineers	Lance-Corpl.
[illegible], H. H.	Royal Engineers	Cadet
Deedes, J. G.	Royal Engineers	Captain
Dixon, F.	Royal Garrison Artillery	[illegible]
Ethelston, S.	Royal Field Artillery	Lieutenant
[illegible] W.	Royal Engineers	Corporal
Fisher, R. E. S.	Royal Engineers	2nd Lieut.
Fiske, A. R.	Royal Engineers	Lance-Corpl.
Hannam-Clark, H. C.	Royal Engineers	Lieutenant
Hindom, H. J.	Royal Flying Corps	Air Mechanic
Holland-Pryor, R. M. C.	Royal Navy	Lieutenant
James, E. G.	Royal Engineers	Lance-Corpl.
[illegible] J. W.	Royal Engineers	Lieutenant
Lee, H. J.	Royal Engineers	2nd Corpl.
[illegible]	Machine Gun Corps	Lieutenant
[illegible]	Royal Naval Air Service	Flight Lieut.
[illegible]	Army Service Corps	Lance-Corpl.
[illegible]	London Regt.	Sergeant
Pernet, F. H.	Royal Engineers	2nd Corpl.
Protheroe, E. L. M.	Royal Field Artillery	Lieutenant
Ripley, H. S.	Royal Flying Corps	Lieutenant
[illegible] J. N.	Royal Engineers	2nd Lieut.
Rodwell, J. T.	Royal Flying Corps	Captain
[illegible] D. H.	Royal Flying Corps	2nd Lieut.
Smith, R. H.	Royal Engineers	2nd Lieut.
Spring-Smyth, H. W.	Royal Engineers	Captain
Stephens, C. A.	Royal Engineers	Lieutenant
Stoneham, C. D.	Royal Engineers	Actg. Capt.
Tabor, A. R.	Royal Field Artillery	Actg. Maj.
Welch, J. G. L.	Royal Garrison Artillery	Actg. Capt.

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FREQUENCY CHANGERS.

By R. TOWNEND, Associate Member.

(*Paper first received 5 October, and in final form* 18 *December*, 1916; *read before* THE INSTITUTION 8 *February, and before the* MANCHESTER LOCAL SECTION 13 *February*, 1917.)

Very little appears to have been written in this country on the subject of frequency changers, and as this type of machine will doubtless receive more consideration in the future than has hitherto been the case—in view of the interest now being taken in the question of the linking up of power stations—a consideration of the various points connected with the use of frequency changers may be of interest to the members of the Institution.

It is not proposed in this paper to consider the problems connected with the use of frequency changers for the purpose of linking up power stations, as this has been done by a paper recently read before the Institution,* but to consider the questions involved in the use of frequency changers as electrical machines.

Frequency changers may be divided broadly into three classes:—

(1) Where the electrical energy is converted electromagnetically from one frequency to the other (by transformer action).
(2) Where part of the energy is converted electromagnetically and the remainder converted into mechanical energy, and then, in some cases, back again into electrical energy.
(3) Where the energy is converted into mechanical energy, and then again into electrical energy.

The first of these types has been described in a paper read before the Institution,† but, as the only ratio of frequency conversion obtainable is 1 to 3 (or multiples of this value) its scope is limited. It is to the second and particularly the third type that the author proposes to limit this paper.

The second type usually takes the form of an induction motor mechanically coupled to some form of driving motor. If an electromotive force having a certain frequency is applied to the stator terminals of a slip-ring induction motor, the rotor of which is fixed so that it cannot rotate, the motor operates as a transformer, the slip-ring voltage being determined by the ratio of the number of turns in the stator and rotor windings, and its frequency being the same as that of the stator supply. If the rotor is allowed to rotate, its speed being held constant at any desired value, either by a friction brake or by coupling it to a generator, the rotor frequency is reduced and is equal to

$$\text{Stator frequency} \times \frac{(\text{Synchronous r.p.m.} - \text{Operating r.p.m.})}{\text{Synchronous r.p.m.}}$$

If the rotor is rotated by means of a driving motor in the opposite direction to that in which it normally tends to rotate, the rotor frequency is increased and is equal to

$$\text{Stator frequency} \times \frac{(\text{Synchronous r.p.m.} + \text{Operating r.p.m.})}{\text{Synchronous r.p.m.}}$$

If we assume a supply frequency of 25 cycles, and the rotor is rotated at 140 per cent of synchronous speed in the opposite direction to that in which it normally tends to rotate, the rotor frequency is $25 + 1{\cdot}4 \times 25 = 60$ cycles, and of the energy taken from the rotor 25/60ths is converted by the transformer action and 35/60ths by generator action, the driving motor supplying the power for the latter portion.

If the rotor were allowed to rotate at half synchronous speed in its normal direction, and neglecting the losses in the machine, of the power supplied to the stator 50 per cent would be given out of the rotor at half the stator frequency, and 50 per cent would be given out mechanically to the direct-coupled machine which now operates as a generator.

With this arrangement it is therefore possible, by using a variable-speed driving motor, to obtain any frequency from zero to a value limited by the maximum safe running speed of the [illegible].

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* J. S. PECK: "The Parallel Operation of Electric Power Stations." *Journal I.E.E*, 1917, vol 55, p. 61.

† A. M. TAYLOR: "Static Transformers for the Simultaneous Changing of Frequency and Pressure of Alternating Currents." *Journal I.E.E.*, 1914, vol. 52, p. 700.

Such a machine appears at first sight to be an almost ideal frequency changer, but it has the great disadvantage of a very poor inherent voltage regulation, its generated voltage falling rapidly with an increase in load particularly at low power factor (due to the large magnetic leakage between the stator and rotor windings), and in order to maintain a constant voltage across the secondary terminals of the machine some form of regulating transformer with automatic regulator is necessary.

The machine being of the induction type takes a lagging current from the supply mains, but this can be overcome (provided no variation in the ratio of frequency transformation is required) by making the auxiliary driving motor of the synchronous type and running it over-excited with a leading power factor sufficient to counteract the lagging current taken by the induction machine.

Its bad inherent voltage regulation has prevented this type of machine from being used commercially to any extent, but it is certainly a very useful form of frequency changer for experimental or testing purposes where high-frequency power is occasionally required and the question of voltage regulation is of little importance.

The third type of frequency changer consists of an alternating-current motor driving a synchronous alternating-current generator. The motor may be either of the induction or of the synchronous type, the former giving what we will call the induction frequency changer, and the latter the synchronous frequency changer. The generator may be of the induction type, but this is very seldom adopted owing to the well-known disadvantages of generators of this type.

As the motor and generator are not electrically connected together, each machine can be designed for any desired voltage and number of phases, so effecting a change in both voltage and number of phases, in addition to the change in frequency, if this should be required. It is thus possible to obtain single-phase power at a low frequency for traction work from a polyphase high-frequency supply without unbalancing the latter. Also by controlling the generator voltage by means of an automatic regulator, its pressure can be maintained constant independent of variations in either the voltage or frequency of the supply.

Maximum Speed of Operation.

The number of poles on the motor and the generator must have the same ratio as the motor and generator frequencies (neglecting the slip in the case of the induction frequency changer), and this of course determines the maximum speed for which the set can be designed. Thus a set converting from 25 to 50 periods may have a 2-pole motor and a 4-pole generator, giving an operating speed of 1,500 r.p.m., whereas a set converting from 25 to 60 periods has a maximum speed of 300 r.p.m., corresponding to a 10-pole motor and a 24-pole generator. If, however, it is permissible to lower the 25-period supply to 24½ periods and raise the 60-period supply to 61¼ periods, a speed of 367½ r.p.m. could be obtained, corresponding to a 8-pole motor and a 20-pole generator.

In the case of the induction frequency changer, the ratio of the two frequencies varies to a small extent with the load, due to the varying slip of the induction motor, and with the number of poles just mentioned an exact conversion ratio of 25 to 60 periods would be obtained at a load corresponding to a motor slip of 4 per cent.

Characteristics of Induction and Synchronous Frequency Changers.

The question of whether to adopt induction or synchronous motors depends upon the conditions governing each case. If it is essential that the ratios of the frequencies should be constant at all loads, that the power factor of the motor should be under the control of the operator, or that the set should be perfectly reversible (by perfectly reversible is meant that the motor will operate as a generator without requiring synchronous machines in parallel with it), it is necessary to adopt synchronous frequency changers. Where these requirements do not apply, the induction set has advantages, particularly from the point of view of the operator, as the paralleling of, and load distribution between, induction frequency changers are usually simpler than is the case with synchronous sets.

Where two stations have to be coupled by means of frequency changers, it may be preferable under certain conditions to use induction sets, as they form a connecting link having the nature of a slipping clutch, whereas synchronous sets have the characteristic of a rigid coupling.

Induction Frequency Changers.

The motor of an induction frequency changer may be of either the squirrel-cage or the slip-ring type; but where induction frequency changers have to operate in parallel, the slip-ring type is preferable.

Starting.—Starting is effected in the manner ordinarily adopted for induction motors; if of the squirrel-cage type, a low voltage is switched on to the stator terminals, and when full speed is reached the starting switch is thrown over to the full-voltage position; with this arrangement the starting current in the line will be approximately 100 to 150 per cent of normal full-load current. In the case of the slip-ring motor, normal voltage is applied to the stator terminals, and the resistance connected across the rotor slip-rings is gradually cut out as the motor speeds up. With this type of motor, the starting current will be approximately 30 to 50 per cent of normal full-load current.

Synchronizing.—Where induction frequency changers have to operate in parallel, the slip-ring type of motor is preferable, as it enables the generator to be synchronized more easily.

Considering the case where a frequency changer running on no load has to be paralleled with a similar set carrying full load, owing to the slip of the induction motor varying directly with the load, the incoming set will be running at a higher speed than the loaded set, and in order that the generators may be safely paralleled it becomes necessary to increase the no-load slip of the incoming set to a value approximately the same as that of the loaded set. If the fully-loaded machine has a slip of 3 per cent, the incoming machine will have a slip of approximately 0·2 per cent (assuming the resistance of the rotor circuits to be the same in each case) and if the generators have a frequency of 50, a synchroscope connected to the two generators will make a complete revolution in 0·71 second, under which condition safe paralleling is an impossibility. It is therefore necessary to increase the slip of the incoming machine before the paralleling can be effected.

This increased slip may be obtained either by artificially loading the incoming set, or by increasing the resistance of the rotor circuits of the motor. If the motor is of the squirrel-cage type, its rotor resistance is fixed, and it is therefore necessary to adopt the first method in order to obtain the desired slip.

In the case of the slip-ring motor, the second method can be adopted, and is obviously more desirable than having artificially to load the machine. It should be noted, however, that as the motor is running on practically no load, the resistance required in the rotor circuit is considerably higher than is usually supplied for starting the set.

An alternative method, which is frequently adopted when paralleling induction frequency changers, is to allow the incoming machine to run up to full speed, and when the generator is giving its correct voltage, power is cut off from the motor, and the generators paralleled at the instant the frequency of the incoming generator falls to that of the loaded machine.

Load distribution.—When two or more sets are operating in parallel, the load taken by each will depend upon the full-load slip of the different motors, and if a distribution proportional to their relative capacities is desired, each motor must have the same percentage slip at full load.

With slip-ring motors this can be obtained by means of the external resistance in the rotor circuit, but as this precludes the use of brush-lifting and short-circuiting gear, it is desirable that the motors should be designed to have the correct slip with the slip-rings short-circuited.

With slip-ring motors, the load can be distributed as desired between the different sets, but with squirrel-cage motors this cannot be achieved, as each set must carry a definite proportion of the total load, dependent upon its slip at full load.

Reversibility.—The induction frequency changer can transmit power in the reverse direction, i.e. with the induction machine running as a generator, provided there are synchronous machines running in parallel with it, having a capacity large enough to supply not only the wattless current required to magnetize the induction machine, but also the wattless component of the total load on both the induction and synchronous machines.

When operating as a generator, the induction machine must run above the synchronous speed, and as in the case when motoring, the slip varies with the load, equal slips above and below the synchronous speed corresponding to equal outputs as generator and motor respectively.

In order to obtain the advantages of the induction frequency changer, and at the same time to obtain perfect reversibility, two induction sets may be used; one set having a low-frequency induction machine coupled to a high-frequency synchronous machine, and the other a high-frequency induction machine coupled to a low-frequency synchronous machine. A pair of frequency changers of this type has been installed in South Wales to link up two stations generating at frequencies of 40 and 50 periods. The stations were of a capacity sufficiently large to make the adoption of synchronous sets undesirable, but it was necessary that the frequency changers should be able to operate in the case of either station being unable to supply power. One set consists of a 10-pole synchronous machine coupled to an 8-pole induction machine, and the other set of a 10-pole induction machine coupled to an 8-pole synchronous machine. The combined output of the two sets is 1,000 kw., the k.v.a. output being limited by the k.v.a. capacity of the synchronous machines, owing to the synchronous generator having to supply the magnetizing current of the induction generator in parallel with it, and also the wattless component of the combined output of the two machines.

The induction machines were adjusted by means of rotor resistances to have the same slip at equal loads, and the two sets then worked perfectly well in parallel, automatically supplying load to either system as occasion demanded.

SYNCHRONOUS FREQUENCY CHANGERS.

The study of the operation of synchronous frequency changers is considerably more interesting than that of the induction type: the starting and synchronizing is a more complex proposition, and the distribution of load between frequency changers operating in parallel may be a matter of some difficulty. In order to investigate these difficulties, it will be necessary to consider how the load on a synchronous machine affects the phase displacement between the terminal and the generated or back electromotive force.

Angular displacement.—If a synchronous generator is running on no load, its generated E.M.F. is in phase with the terminal E.M.F., but when loaded these two electromotive forces may no longer be in phase, due to the resistance and inductive drop in the windings. This displacement is shown vectorially in Fig. 1 for a load having a power factor of 100 per cent:—

O A is the terminal E.M.F., and as the load has a power factor of 100 per cent, the current is also in phase with O A.

A B is the resistance drop in the windings (in phase with the current).

B C is the inductive E.M.F. (leading 90° with respect to the current).

O C then gives the phase direction of the generated E.M.F., leading with respect to O A by the angle a.

Fig. 2 shows a similar diagram for a load having a power factor of 80 per cent lagging.

Similarly in the case of a loaded synchronous motor, the back E.M.F. will lag with respect to the terminal E.M.F. by an angle which we will call β. We see, therefore, that when the frequency changer is loaded, its generator terminal E.M.F. will lag behind its no-load position by an angle of $a + \frac{(\beta - \beta_1) \sim_G}{\sim_M}$, where β_1 is the no-load value of β, and $\sim_G$ and $\sim_M$ are the respective frequencies of the generator and motor.

In Figs. 1 and 2 the value of A B is small compared with O A, and has therefore very little influence on the angle a. B C is approximately proportional to the armature current, and therefore where a is small it is approximately propor-

[illegible] the output of the machines if the voltage remains [illegible].

We will now consider the case of a frequency changer converting from 25 to 50 periods, and we will assume that at full load cos φ = 1 (all the following angles are measured in electrical degrees) and $\beta = 25^\circ$. The load on the motor when the set is running light we will take as 10 per cent of the full load. Then on no load $\beta_1 = 2{\cdot}5^\circ$ and $\beta = 25^\circ$, assuming the angular displacement to be proportional to the loads.

Due to the ratio of the frequencies of the motor and generator, the no-load displacement β_1 of 2·5° corresponds to a displacement α of 5° between the actual generator terminal E.M.F., and the generator terminal E.M.F., which would be obtained if $\beta_1 = 0$, i.e. if the no-load losses were zero. On full load the motor displacement β of 25° corresponds to a generator displacement of 50°, and therefore the total angular displacement between the no-load and full-load generator voltage is $50^\circ - 5^\circ = 45^\circ$. That is to say, if one set is operating at full load and a similar set has to be paralleled with it, the terminal E.M.F. of the incoming machine will be 45° ahead of that of the loaded machine when the generators should be synchronized, and when this is done the sets will divide the load equally.

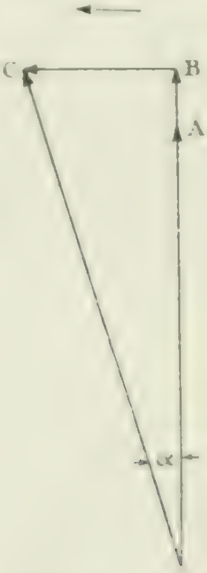

FIG. 1.

If the 50-period machines are synchronized before the 25 period machines, the latter will be 34′ out of phase when they would be synchronized.

The paralleling of machines when out of phase causes a heavy momentary rush of current and severe mechanical stresses in the stator windings and other parts of the machines, the value of these stresses increasing with the amount by which the voltages are out of phase. If two similar machines are paralleled with their voltages 180° out of phase, the rush of current and mechanical shock will be the same as if each machine had been short-circuited [illegible].

It is of course desirable to keep these stresses as low as possible, and it is therefore an advantage to synchronize the high-frequency machines before those of the lower frequency. A still more satisfactory arrangement is to build the frequency changers with either the motor or the generator stators rotatable through a small angle, either by means of a hand-wheel (similar to the brush-rocking gear of a continuous-current generator) or by a small motor suitably geared to the stator. The stator of the incoming machine can then be rocked round until the generator voltages are in phase, and then rocked in the opposite direction until the set takes the desired load.

It is interesting to note in the case of frequency changers converting from a low to a considerably higher frequency, and when the low-frequency machines are paralleled first, that the incoming generator may be 180° out of phase with the loaded generator. With such a condition, correct paralleling is of course impossible unless the machines have movable stators, or unless the incoming machine is artificially loaded before paralleling.

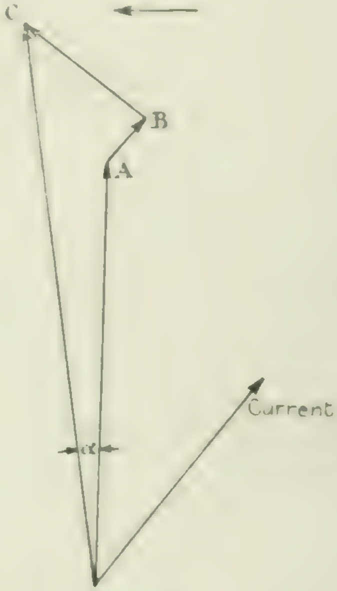

FIG. 2.

Load distribution.—It is well known that when alternators are operating in parallel, the load taken by each machine is, to all intents and purposes, not affected by the field excitation. A change in the field current of one machine causes a wattless current to flow through the different machines, this wattless current having such a value that its magnetizing or demagnetizing action on the machines will almost neutralize the change made in the field current.

If two exactly similar frequency changers are operating in parallel, the total load will be divided equally between them, and any change in the excitation of one generator will only alter the power factor at which each generator is operating, the kilowatt output of each machine remaining practically the same as before. (It is possible to make slight variations in the load by field variation, due to the change in wattless current increasing or decreasing the losses in the generator, but as the variation is only a few per cent of the normal output, it may be left out of consideration.)

In order to make one generator take more load than the other, it is necessary to make the generated E.M.F. of the former lead with respect to the E.M.F. of the latter, and this is accomplished by turning the stator of the former generator through a small angle in a direction against the rotation, by means of the rocking gear already referred to.

It may be mentioned that a division of the load proportional to the normal output of the different sets is usually desirable, as it generally gives the highest overall efficiency.

Design of machines required to operate in parallel.—When designing frequency changers which have to operate in parallel, care should be taken that all the sets have as nearly as possible the same phase displacement between the motor and generator terminal electromotive forces at full load, otherwise the load distribution between the different sets will vary with different total loads.

We will consider the case of two sets of equal capacity, one having a total full-load angular displacement of 40° (expressed in terms of the generator displacement) and the other of 60°, the sets being adjusted so that their generator voltages are exactly in phase when both machines are running on no load. If the sets are operated at a total load equal to their combined full-load outputs, they will divide the load so that the former set carries approximately 3/5ths of the total load (i.e. it operates at 20 per cent overload) whilst the latter set will carry approximately 2/5ths of the total load (i.e it operates at 80 per cent of its rated capacity).

In order to make each set operate at full load, it will be necessary to move the stator of the overloaded generator approximately 20 electrical degrees forward in the direction of rotation, or the stator of the other generator backward a similar amount.

With this new adjustment, if the total load be reduced to zero, the latter set will reverse, the motor operating as a generator, and the generator as a motor, power being circulated round the two frequency changers.

In addition to the correct electrical design, it is also necessary that frequency changers which have to operate in parallel should be so built that when the motor voltages are in phase the generator voltages are also in phase. This, of course, is easily achieved if either the motor or the generator stator be made rotatable. If fixed stators are adopted the sets can be made exact mechanical duplicates, but to do this involves considerable difficulties (due to the necessary accurate location and machining of keyways, stator slots, coupling bolt holes, etc.). It is therefore advisable to make the sets approximately similar and to provide some means for final adjustment, e.g. the couplings may be temporarily fitted with small bolts, and after the machines have been tested for phase position and any correction made, the couplings can be re-drilled and the correct bolts fitted.

In order to ascertain if the generator voltages of two frequency changers are in phase when the motor voltages are in phase, a simple method is to run the motors in parallel, and connect terminal A of one generator to the corresponding terminal A_1 of the other generator. Both generators are then excited to give exactly equal voltages, and the voltage measured between terminals B and B_1, or C and C_1, will indicate the amount by which the generators are out of phase. These voltages can be plotted graphically to obtain the angle through which one generator stator should be rotated to bring the voltage exactly into phase.

An alternative method is to run the two sets with both the motors and generators in parallel, an ammeter being connected in one phase of the generators. Both generators are then excited with approximately normal field current, the excitation of one being then adjusted so that the alternating current flowing between the two generators is a minimum. If the generated voltages are exactly in phase, this minimum will be zero.

Starting.—The starting of synchronous frequency changers can be effected either by means of a mechanically-coupled starting motor or by making the synchronous motor (or if desired the generator) self-starting and self-synchronizing.

Starting by separate starting motor.—If a separate starting motor is adopted it is usually of the induction type, and may have either a squirrel-cage or a slip-ring rotor, the latter being desirable for large units owing to the smaller momentary starting current required. The starting motor is usually built with one pair of poles less than the synchronous motor, and the rotor resistance is adjusted so that the set runs slightly above synchronous speed when the synchronous motor is excited to give normal voltage; the speed is finally adjusted to the correct value by exciting the generator.

Self-starting synchronous motor.—If the separate starting motor be dispensed with, and the synchronous motor be made self-starting,* the starting current will be increased, but as the machine is self-synchronizing this operation is considerably simplified. During the starting period the synchronous motor operates as an induction motor, the field system being usually fitted with a number of copper or brass bars embedded in the pole faces, the bars being short-circuited at each end by metal rings so forming a complete squirrel cage. If solid steel poles are used, this squirrel cage may be dispensed with, the currents induced in the pole faces giving sufficient torque to run the machine up to speed.

Starting is effected by means of an auto-transformer, a voltage of 30 to 50 per cent of the normal being usually sufficient to give satisfactory starting; the initial line current at starting being about 75 to 150 per cent of full-load current. The slip-rings of the motor should be short-circuited through a resistance during the starting period, in order to prevent a high voltage being induced in the field coils. When full speed is reached, the field is excited and the machine pulls into step, the starting switch being then thrown over to the full-voltage position.

Synchronizing.—When the motors of two identical synchronous frequency changers are running in parallel, the generator voltages will not necessarily be in synchronism, even assuming both sets to be running light.

We will consider the case of two identical frequency changers A and B converting from 50 to 25 periods, the motors having 8 poles and the generators 4 poles. A is running on no load, and it is required to connect B in parallel with A on both the 50-period and 25-period ends.

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* E. Rosenberg: "Self-synchronizing Machines." *Journal I.E.E.*, 1913, vol. 51, p. 62

Fig. 3 shows diagrammatically the positions of the poles on the motor and generator, the radial lines inside the circle representing the centres of the motor poles and the radial lines outside the circle representing the centres of the generator poles.

When the two motors are in synchronism, the N pole 1 of motor B can occupy four positions with respect to the N pole 1 of motor A, viz. positions 1, 3, 5 and 7, but in only two of these positions, 1 and 5, will a N pole of generator B occupy the same relative position as a N pole of generator A. That is to say, with the motor pole 1 in positions 1 and 5, the generator voltages will be in phase, but with positions 3 and 7 the generator voltages will be 180° out of phase. It is therefore seen that with the ratio of frequency conversion under consideration (2 : 1) the probability of obtaining synchronism between the generators when the motors are in phase is 1 to 2.

If it is found that the generator voltages are 180° out of phase when the motors are in synchronism, this can be corrected by reversing the excitation of one generator. If the excitation of one motor be reversed, it will be impossible to synchronize the generators, as their voltages will be 90° or 270° out of phase.

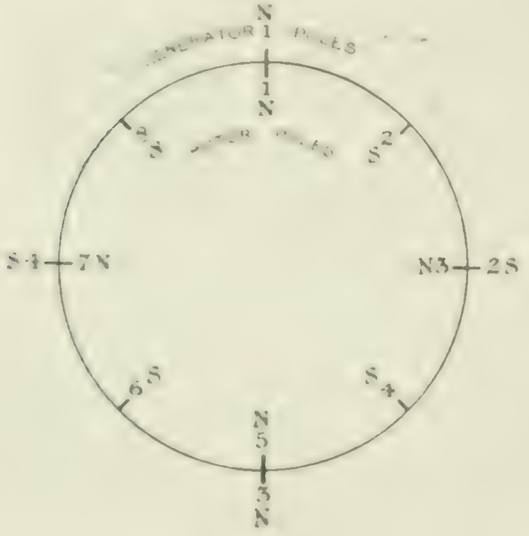

FIG. 3.

If the 25-period machines are synchronized first, it will be seen that the 50-period machine voltages must be in phase every time.

If we consider the case of some other ratio of frequency transformation, say 25 to 60 periods, the probability of obtaining correct synchronism of both motors and generators is considerably reduced. With this case the numbers of poles on the motor and generator are 10 and 24, and Fig. 4 shows the relative position of the centre lines of the poles of the two machines. When the motors are in phase, pole 1 of motor B can occupy positions 1, 3, 5, 7, 9 with respect to pole 1 of motor A, but only in the case of position 1 will the generator voltages be in phase. We thus obtain the chance of 1 in 5 of obtaining correct synchronism of the generators.

If the 60-period machines be paralleled first, the chance of obtaining correct synchronism is 1 in 12, which may be increased to 1 in 6 if the 25-period machines are fitted with a field-reversing switch.

It will be found that the chance of obtaining correct synchronism is always greater if the low-frequency machines are synchronized before the high-frequency machines, but as already pointed out when a set has to be paralleled with one already on load it is an advantage to synchronize the high-frequency machines first, in order to reduce the angle by which the loaded and unloaded machines are out of phase, so reducing the rush of current at the moment of switching in.

Methods of obtaining correct synchronism.—In order to obtain correct synchronism of both motors and generators, one of two methods may be adopted :—

(1) Where the motors and generators are synchronized simultaneously.

(2) Where the motors and generators are synchronized separately.

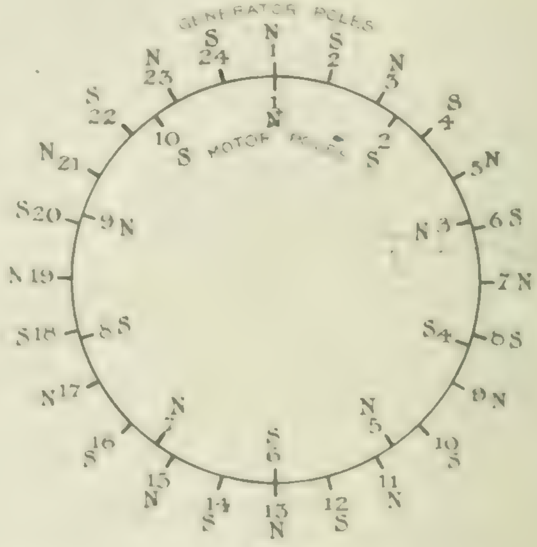

FIG. 4.

(1) This method is usually only possible when a separate starting motor is used, because a self-starting synchronous motor will usually pull into step without field excitation, and therefore there is no control over the instant at which it will pull into synchronism.

The most satisfactory arrangement is to have a synchroscope fitted with two pointers, one controlled by the high-frequency and the other by the low-frequency machine. As the machines approach synchronism, the two pointers will rotate at different speeds proportional to the respective slips of the incoming machines controlling them, and the motors should be paralleled when the two pointers simultaneously indicate synchronism.

(2) The motor is first paralleled and the synchroscope connected to the generator : the pointer of the synchroscope will of course remain stationary at a position on the dial indicating the phase difference between the busbar and the generator voltages. The motor excitation is then reversed so causing the motor to "slip a pole," when the synchroscope pointer immediately takes up a new position

This operation of reversing the motor field current is repeated until the synchroscope indicates synchronism, when the generator can be switched on to the busbars.

If the motor is of the self-starting type, it is advisable to perform this operation of pole-slipping when the motor is running at the reduced starting voltage, as this causes a smaller kick in the line current and less shock to the motor.

Synchronizing loaded with unloaded machines.—It is important to note that when synchronizing the generators in the way just described, the position taken up by the synchroscope pointer will vary with the output of the loaded machine, due to the angular displacement (due to the load) between the motor and generator busbar voltages as previously explained. This can be taken care of by fitting the synchroscope with a zero mark, which can be moved over a scale graduated in kilowatts output of the running machine. Before synchronizing the incoming machine, the zero mark is moved to the mark on the scale corresponding to the output of the loaded machine, and when the pointer is opposite the zero mark the incoming machine is in the correct phase for paralleling.

Effect of interconnecting the terminal leads.—We have already considered the different amounts by which the generator voltages can be out of phase, depending upon the number of poles on the motors and generators, but these considerations have been made on the assumption that the connections between the motor and generator stator terminals and the busbars have remained unchanged. With polyphase machines there is, however, the possibility of obtaining a greater number of out-of-phase positions than those already considered, by changing the connections between the stator terminals and the busbars. This additional complication need not be considered when the set is installed and permanently connected up, but it will be seen that in the case of a frequency changer, where neither machine has a rotatable stator, if it is impossible to synchronize the generator correctly, due to faulty machining, etc., the amount by which the voltages are out of phase may be reduced by changing the connections between the stator terminals and the busbars.

Considering the case of a 10-pole three-phase motor driving a 24-pole three-phase generator, and assuming the motor to be synchronized before the generator, we obtain the following angles by which the generator and busbar voltages can be out of phase, assuming no load on the busbars :—

PHASE ANGLE BETWEEN THE GENERATOR AND BUSBAR VOLTAGES.

Position	Motor Excitation	Generator Excitation	
		Normal	Reversed
1	Normal	0°	180°
2	Reversed	$\frac{24}{10} \times 180° = 432° = 72°$	252°
3	Normal	144°	324°
4	Reversed	216°	36°
5	Normal	288°	108°
6	Reversed	360° = 0°	180°

These figures are based on the assumption that terminals A, B, C on both motor and generator are respectively connected to busbars A, B, C.

If we connect the generator terminals B, C, A to busbars A, B, C respectively, the figures given in columns 3 and 4 will be increased (or decreased according to the phase rotation) by 120°. If we connect terminals C, A, B of the generator to busbars A, B, C respectively, the figures in columns 3 and 4 will be increased (or decreased) by 240°. We thus obtain the following possible amounts by which the generator and busbar voltages may be out of phase :—

PHASE ANGLE BETWEEN THE GENERATOR AND BUSBAR VOLTAGES.

Position	Motor Excitation	Generator Excitation					
		Normal			Reversed		
		Busbar Terminals A, B, C connected to Generator Terminals					
		A, B, C	B, C, A	C, A, B	A, B, C	B, C, A	C, A, B
1	Normal	0°	120°	240°	180°	300°	60°
2	Reversed	72°	192°	312°	252°	12°	132°
3	Normal	144°	264°	24°	324°	84°	204°
4	Reversed	216°	336°	96°	36°	156°	276°
5	Normal	288°	48°	168°	108°	228°	348°

By this means we obtain 30 possible positions 12° apart, and therefore, with the maximum possible error in machining or winding, it is possible to obtain an out-of-phase angle between the generator and busbar voltages which will not be greater than $\frac{1}{2}(12°) = 6°$.

COMPARISON BETWEEN INDUCTION AND SYNCHRONOUS SETS.

There is very little to be said in the way of comparison between the two types of machines, from the point of view of cost, efficiency, overload capacity, reliability, maintenance, and floor space, as in these respects they are practically on an equality (assuming the same synchronous speed with each type). The type to be adopted must therefore be determined by the other characteristics of the machines, which may be tabulated as given in the table on page 204.

It may appear from the foregoing pages that the difficulty and troubles to be experienced in connection with the operation of synchronous frequency changers are sufficiently great to make it advisable to avoid this type of machine if at all possible. The above comparisons and a close consideration of the subject, however, will show that these difficulties are not as real in practice as one would at first expect. If either the motors or the generators are fitted with rotatable stators, the synchronizing and load distribution are as simple, or even simpler, than with induc-

[illegible] frequency changers. If the machines have [illegible] rotatable stators, the difficulty of synchronizing depends to a great extent on the ratio of frequency conversion. In [illegible]

[illegible] cycles [illegible]
[illegible]
50 .. 40 .. 1 .. 5

[illegible] "[illegible] poles" by

	[illegible]	[illegible]
Power factor of motor	Cannot be controlled and always lagging [illegible]	Motor can be designed to operate at any [illegible]
[illegible]	Reversible only when synchronous [illegible] the induction machines	Perfectly reversible
Ratio of frequency transformation	Varies slightly with the load	Constant at all loads
Starting current	[illegible] of full-load line current. Slip-ring motor [illegible]	[illegible] full-load line current. Separate induc- [illegible] of full-load line current
Synchronizing of motor	Does not run in synchronism	[illegible] of motor is used Necessary if separate starting motor is used
Synchronizing of generator ...	Objectionable with squirrel-cage motor. Not difficult with slip-ring motor	Simple if stator-rocking gear is provided Simple, but may take longer if rocking gear is not provided
Distribution of load between [illegible]	Impossible with squirrel-cage motors Simple with slip-ring motors	Impossible with fixed stator Simple if stator-rocking gear is provided

correct synchronism (taking advantage of the effect of reversing the generator excitation) are as follows:—

25 to 40 cycles 1 in 5
[illegible]
[illegible]

reversing the motor excitation is easily carried out, and will quickly bring the generators into the correct phase relation for paralleling.

Taking all the points into consideration, the advantages of the synchronous frequency changer are sufficient to justify its adoption in the majority of cases.

APPENDIX

[illegible]

[illegible]

[illegible]		[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	600

Discussion before The Institution, 8 February, 1917.

Mr. G. W. Partridge: Now that the question of linking up is so much before us, the subject of frequency changers is of very great importance. I am sorry that the author has not referred to phase changers in the paper, as the question is of great interest. I should like to ask him whether the distribution of load between frequency changers could not be effected by using automatic regulating transformers instead of by rotating the stator, as it appears to me that it is a question of altering the inductive drop on the particular set in question. I should also like him to refer to the statement on page 199 in regard to the alternative method of paralleling by means of switching over the motor; this, in my opinion, will cause a rush of current when the motor is reconnected again to the circuit, in all probability damaging the end coils of the stator windings. My company has several large induction motor-generators in use, and when we first switched the current on to the stator of the induction motor we had a rush of current which damaged the coils. All these motor-generators are now switched in through a water resistance. To rotate the stators of frequency changers might be satisfactory in small sets, but I scarcely think it would be practicable with very large sets. Can the author say whether a method of moving the stator so as automatically to keep the load constant, even if the periodicity of the two supplies varies, has been devised? I should also like to ask him whether he has considered the possibility of using a flexible magnetic coupling between the sets. With regard to synchronizing and switching in these sets, it occurs to me that it might be possible to do that by means of a water resistance and an oil switch; that is to say, to switch on the set through the resistance in the first instance, then gradually bring it into phase and short-circuit the resistance by means of the oil switch. Such an apparatus might also be used for disconnecting the set in the event of any disturbance on the two supplies. On reading the paper I found it very difficult to make up my mind whether the author advocates the synchronous or the induction type of frequency changer. The reference on page 199 to two stations in South Wales seems to give the impression that if the generating stations are of large capacity synchronous sets are undesirable. Does he mean that the capacity of the stations is large compared with the frequency changers, or that the capacity of one station is large compared with the other? Taking everything into consideration, particularly the size of the frequency changers, which I think will increase to a very large extent, and also the capacity of the different systems to which they are connected, I consider that the induction frequency changer would be preferable. I think there would be less danger of it falling out of step if any disturbance on the system took place. It would be simpler to work, simpler to design, and stronger from a mechanical and electrical point of view. For the last six years I have had experience of a 1,500 kw. set, and it may be of interest if I mention some further particulars of it. The speed is 365 r.p.m. It consists of a three-phase induction motor with a wound rotor having 8 poles, which is connected to a single-phase synchronous machine having 28 poles. We had the synchronous machine provided with damper windings, because we wanted it to run as a motor if necessary. The slip of the motor on full load is from $2\frac{1}{2}$ to 3 per cent, and the overall efficiency of the set is $86\frac{1}{2}$ per cent. The set was made by the British Westinghouse Company, and every guarantee which they gave has been fulfilled. Either side of the set is used to generate current. It is synchronized by running up on the induction motor in the first instance, and then the speed of one or other of the prime movers is varied before synchronizing. It normally runs with the three-phase motor driving the single-phase generator. This single-phase generator is provided with a Tirrill regulator, and one set keeps the whole of the pressure on the lighting system constant, no matter how many generators are synchronized with it. The switchman, as soon as he synchronizes the steam sets and puts them on the busbars, has nothing further to do in altering the regulating resistances, as the whole of the pressure of the lighting system is kept constant by this one motor-generator. This set has been running for about six years, and up to the present it has never given any trouble.

Mr. J. S. Highfield: Mr. Partridge has said that at the present time there are very few engineers in electric power stations who are not considering the question of linking up. Unfortunately we always meet with the great difficulty of differences in frequency. It is a surprising thing that it was not until comparatively recent times that the importance of standardizing frequency was recognized. It was appreciated at the beginning of the industry that pressure should be standardized. Dealing with the facts as they are, I find in one small area frequencies of 60, 90, 40, 50, and 75. To enable linking up to be done in these circumstances, frequency changers would certainly be necessary in the early stages, but I consider that as soon as possible, rather than spend money on these machines, the frequency should be standardized. The problem of the frequency changer is not quite as simple as it looks. As a rule it is desirable to link up two or three systems which are more or less of equal size, so that the link will enable any station to supply the others. In that way the supply is a reciprocal one. One of the chief advantages of linking up several stations is that the load can easily be a greater proportion of the plant installed; that is to say, the total amount of spare plant can be reduced, because, when linked up, it is not very difficult to shut down a station for a few days in order to carry out overhauls in a very thorough way. To link up two or more systems so that the supply can be mutually interchangeable involves the use of synchronous frequency changers. I think it would be very interesting if the author could give a few examples of jobs where linking up has taken place. I have no experience of the conditions, but I cannot think that very satisfactory operation would be found between two stations situated some distance apart and connected together through the shaft of a frequency changer where reciprocating engines were used at one or both of the stations, although it might be quite workable with turbines. In many of the stations in this country, however, numbers of reciprocating engines are still in use. No doubt the method of rocking the stator very much simplifies the [illegible] of putting back [illegible]. In the future I [illegible] that frequency changers will be used on a considerable scale to link up between 50-cycle and 25-cycle [illegible] I said before I think the final and proper solution is to reduce the number of odd frequencies. I think that when additional plant is required for stations not of standard frequency, the most careful consideration should be given to the problem, even if the immediate expenditure is considerably more to buy new plant of constant frequency. I am sure that very often the money would be well spent.

Professor Robertson

Professor D. Robertson (communicated): Besides the synchronous and asynchronous frequency changers described in the paper, there is another possibility which does not seem to have been previously put forward but which appears to possess all the advantages of the continuous-current method without the great disadvantage of the great cost and large losses of that method. If current from an external source be fed into the rotor of an induction machine it acquires all the properties of a synchronous machine, for the rotor tends to keep its flux axis in line with that of the stator. When the injected current is continuous, the machine operates exactly as an ordinary alternator. When polyphase alternating current is used, the rotor flux rotates relatively to the rotor at a speed determined by the injected exciter frequency, and the synchronous speed will be greater or less than its former value by that amount. We thus get a synchronous machine the speed of which is not determined by the number of poles, but can be controlled by adjusting the exciter frequency, which is very easily done if the exciter is driven by a continuous-current motor. Such a machine may be termed a semi-synchronous machine. It could be started up just like any slip-ring induction motor. When it is transmitting power, the exciter must contribute to, or take from, the main power an amount depending on the load and the difference between its speed and the natural synchronous speed. Two such machines, running at the same speed and coupled together mechanically, can act as a link between two systems whether their frequencies are the same or not. Used as a frequency changer, the set does not tie the ratio of the frequencies to an exactly constant value fixed by the number of poles. Relative changes of frequency are permitted by a slight change of the speed of the exciters. If the double synchronous set is compared with a rigid coupling, the asynchronous set is a coupling which only transmits power when it slips, while the semi-synchronous set is a coupling which need not slip and will not do so when the frequency ratio is constant, but is capable of doing so without injury or waste of power when necessary. The size of the exciters is a minimum when the set is worked as near to the natural synchronous speed as possible; by having them larger we may have a considerable discrepancy between the ratio of the poles and of the frequencies, and thus complicated frequency ratios are quite easily dealt with, or numbers of poles and speeds more favourable to the design of the main machines could be chosen than would otherwise be possible. When no power is being transmitted through the set, the magnetic axis of the rotor of each machine must be in line with that of its stator. By retarding or advancing one of the exciters, which only requires a change in the field regulator of its motor, the main machines can be made to act respectively as motor and generator. The amount of load exchanged between the two systems is thus under complete control without access to the engine stop-valves, and there does not appear to be any difficulty in arranging for it to be done automatically. At the same time, the power factor of the current taken from each system can be independently controlled, either by hand or automatically, by adjusting the field of the exciter itself. Such a semi-synchronous set would thus give far more complete control than either the synchronous or asynchronous sets; provided the exciters are not made too small, it would permit quite a large drop of frequency on one system, owing to accident, without disturbing the other system, or danger to itself. The size of the set would thus be settled by the amount of power to be interchanged rather than by that load which might come on it in the event of a breakdown in one system. In the event of such a breakdown causing a total shut-down on one system, the circuit breaker on the exciter motor would come out long before the decrease in frequency was sufficient to cause trouble with the frequency changer. The exciters would be small, unless it was intended to permit a considerable difference between the frequency ratio and that set by the number of poles. They probably would not need to be rated at much over 5 per cent of the main machine in ordinary cases, and so would not add a very great proportion to the cost. The low-frequency currents required for excitation could be obtained from a low-frequency alternator of the ordinary type, or from the rotor of an induction machine the primary of which is excited from one of the main systems through a regulating transformer, while the rotor is held at the correct slip by means of the continuous-current motor. The latter arrangement would give a more favourable speed for the continuous-current motor than the former, but there has not been time to work out all the details of the system. Neither has it been possible to examine all the possibilities which it opens up, but it would appear probable that, at least when the frequency ratio is the same as the number of poles, both exciters could be driven by the same motor. They would have different numbers of poles, and consequently an advance of the common shaft would advance the phases by different amounts and give the phase difference necessary for taking up load. Such an arrangement would, at least with synchronous exciters, cut down the size of the exciter motor to a very small amount, as it would never have to deal with part of the main power, for while one exciter was acting as a generator, the other would be motoring by an approximately equal amount.

To sum up, the semi-synchronous set would seem to promise complete control of both the load and the power factor, to be entirely free from risk of injury by a shutdown on either system, an ease of starting comparable with that of a slip-ring induction motor, smooth parallel running with other machines of any type, and a complete independence of the two systems so far as exact frequency ratio and phase are concerned, while at the same time its cost would not very greatly exceed that of the cheapest sets now available. In fact, seeing that its rating need not bear a minimum ratio to the total power of the smaller system, it would probably be much cheaper than any other when the maximum power to be exchanged is only a small fraction of the load on the smaller system.

Mr. Townend.

Mr. R. Townend (*in reply*): I agree with Mr. Partridge that the subject of phase-changing and phase-balancing is one of great importance and interest, and it certainly demands a paper to itself. I understand that a paper on this subject has been almost completed and will be submitted to the Institution next session.

Choke coils could be used for varying the load distribution between synchronous frequency changers, but to do so would involve additional apparatus and would not be so simple as using a rotatable stator. It is quite correct that when pressure is switched on to an induction motor there is a rush of current whether the machine is running or is stationary, and with high-voltage machines it is an advantage to switch on the pressure through some form of variable resistance. It is not a difficult matter to design a stator which can be rotated. This has been done and has proved satisfactory in the case of frequency changers having a capacity of at least 5,000 k.v.a.

In order to use a comparatively small synchronous frequency changer for linking up two power stations, it has been proposed to fit the generator of the frequency changer with a stator which could be rotated continuously in either direction. The rotation of the stator would be effected by means of a small motor, the speed of which would be controlled by the load on the frequency changer. If the load on the frequency changer increased, the motor would rotate the stator slowly in the same direction as the field and so cause the load to be reduced. It would, of course, be necessary to fit the rotating "stator" with slip-rings.

A magnetic clutch could be used between the motor and generator of a synchronous frequency changer, and would simplify the paralleling of two power stations, but such an arrangement could not be used if more than one frequency changer were installed. If one machine were on load, it would be necessary to give the correct angular displacement between the motor and generator of the incoming machine before closing its clutch, in order to make it take its share of the load. There would be no objection to paralleling the incoming generator with one on load through a resistance, in order to avoid the shock which would otherwise occur due to paralleling the two machines when they were out of phase.

The arrangement of induction frequency changers described on page 199 was adopted because the capacity of the power stations was large in comparison with that of the frequency changer.

Mr. Highfield asks for a few examples of where linking-up has taken place by means of synchronous frequency changers. I do not know of many cases in this country where this has been done, but there are many examples in America. Mr. Peck[*] has recently given instances where large power systems both in Italy and America have been so connected. There is no doubt that satisfactory parallel operation between two power stations will be more easily obtained when the generating sets are turbine driven than when reciprocating engines are used, particularly when the two stations are some distance apart. There are several cases where reciprocating stations of the same frequency operate in parallel, and although the introduction of a frequency changer is an additional complication it should not appreciably affect the parallel operation of the stations.

The description given by Professor Robertson of his "semi-synchronous" frequency changer is very interesting. Although more complicated than an ordinary synchronous set, his machine has the great advantage of a variable ratio of frequency transformation.

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[*] J. S. Peck: "The Parallel Operation of Electric Power Stations," *Journal I.E.E.*, 1917, vol. 55, p. 61

MANCHESTER LOCAL SECTION, 13 FEBRUARY, 1917.

Professor Walker.

Professor Miles Walker: I do not believe that any of us thought, before we read this paper, that there was so much of interest to say about the subject of frequency changers. The points which have struck me as of special interest are: the magnification of the angle of displacement, referred to on page 199; the necessity of securing a correct relation between the positions of the poles of the motor and the poles of the generator, mentioned on page 201; and the very large number of possible relations between poles which one can obtain in some frequency changers by interchanging the phases, mentioned on page 203. Not only does the paper itself cover a large number of points of interest, but as one reads it the mind is continually invited to turn to other questions which suggest themselves. For instance, there is the coupling of two power stations by means of a synchronous frequency changer; there, as the author points out, we have a coupling which is analogous to a solid coupling connecting two machines driven by independent prime movers. If we have two large power stations each running at its own particular speed, one, say, at 50 cycles and the other at 40 cycles, we dare not connect them together by means of a synchronous frequency changer, unless the motor-generator has a fairly large output compared with the output of the power station. That, I take it, is one of the great difficulties in the way of using synchronous sets. In cases of that kind, as the author has said, asynchronous sets may be used, and if it is required to circulate power either way, two sets may be installed, one having the synchronous motor connected to the mains of one power supply, and the other having a synchronous motor connected to the other power supply. That is one solution, but I am not at all sure that it is the best. If we are permitted to introduce a commutating machine into the rotor circuit of the induction motor, as was proposed by Leblanc 20 years ago, all sorts of possibilities present themselves to us, not only of controlling the power factor of the induction motor and making it take wattless load as an asynchronous generator, but also of circulating power either one way or the other way through the set, independently of the speed of the connected power stations. For instance, a frequency changer might consist of a 12-pole 50-cycle synchronous generator direct-connected to a 10-pole induction motor connected to the 40-cycle supply. This set would run at 500 r.p.m., so that the induction motor would be running at 4 per cent above synchronous speed, and would tend to deliver power to the 40-cycle circuit. If, now, the rotor circuit of the

Professor Walker.

[illegible] machine can be made to operate as a motor, [illegible] the power factor can be kept near unity [illegible] Moreover, when the asynchronous machine is [illegible] supply a generator load, the phase advancer can be used to supply the wattless component of the load. Several alternative methods of controlling the speeds and loads of induction motors by means of phase advancers, or [illegible]

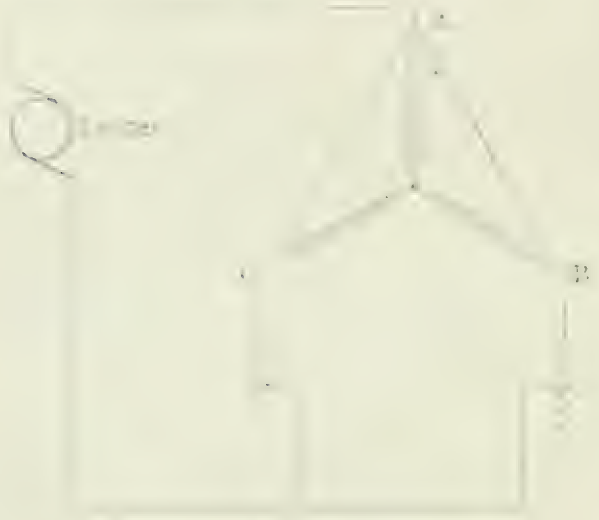

Fig. A.

[illegible] be made considerably smaller than the type comprised in class 3; and, when combined with a Leblanc exciter, this type of frequency changer seems to be very attractive.

The phase advancer in connection with induction motors has not come into use to any very great extent in this country; there is a fear that it is an unnecessary complication. We know already that with proper design [illegible] a synchronous motor, and the future will show many [illegible] which it can be put. If we turn to the [illegible] advantages of the induction type and the synchronous type of frequency changers are compared, we shall find [illegible] type completely changes the conclusion which would [illegible] by the induction type, and [illegible]ection to the rigidity of the [illegible]t to the synchronous frequency changer [illegible] frequency changer is employed, there is another method of changing the load between sets run in parallel, other than that of rocking the stator frames. If the field-magnet of one of the synchronous machines is wound with a polyphase winding, say as a three-phase machine, it is possible to shift the position of the poles of the magnet relatively to the iron, and in this way secure the same effect as is obtained by rocking the stator frame. Fig. A shows how a three-phase generator can be connected to an exciter and two rheostats so as to obtain a shifting of the pole through an angle of 60°. If all the exciting current is passed through phases A and B, the resultant field takes up a position A B; if the current, after passing through A, is equally divided between B and C, the line of the poles is in phase with A; and if all the current is passed through phases A and C, the line of the poles takes [illegible] exciter which will give any required phase position of the excitation on the rotor; and, in cases where perfectly synchronous running is required, the exciter operates as a continuous-current generator. Where, however, it is required slowly to change the pole positions on the rotor in order to produce a slip, the exciter can be operated at the frequency required to produce the desired result.

Mr. Ratcliff.

Mr. H. A. Ratcliff: The paper fully amplifies the difficulties incidental to the operation of frequency changers, which were referred to in the recent paper by Mr. Peck on "The Parallel Operation of Electric Power Stations."† I consider the author correctly sums up in favour of synchronous machines; but they constitute an absolutely rigid connection or coupling between the separate systems, and will therefore have to be large enough to meet any abnormal load conditions, since presumably they will be [illegible] under such abnormal conditions. That being the case they are no doubt designed with a large overload capacity, and some information as to the efficiency of these machines under such conditions would therefore be of interest as they are likely to run for considerable periods at loads considerably lower than the maximum rating. When synchronizing these machines it will be necessary to control the frequency of the prime movers, and for that reason no doubt they will usually be installed in the generating stations and not in distant substations. It may be advisable therefore in certain cases, depending upon the electric characteristics of the line, to consider whether the frequency changers should be installed in the low- or the high-frequency generating station. Although not mentioned in the paper it is presumably not possible to run synchronous and asynchronous machines in parallel, since the latter type depend on speed variation for their load control. Reference is made on page 199 to "an alternative method which is frequently adopted when paralleling induction frequency changers." Apparently the incoming machine is paralleled with a fully loaded one, or, in other words, with a machine having its maximum slip, and consequently the motor of the incoming generator is thrown on to the line when running at a speed corresponding to maximum rotor slip. This must result in a very appreciable and undesirable surge on the line before the machines either run up to a speed corresponding to half-load slip or take up more load,

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* [illegible]

* [illegible]

† [illegible]

depending upon whether or not they are running in parallel with prime movers on the generator side. It would be interesting to know whether large synchronous machines of, say, 1,500 or 2,000 kw. capacity are made with movable stators, as although it appears to be an unmechanical form of construction for machines of such large size, it certainly simplifies the difficulties incidental to synchronizing and the adjustment of load under conditions of parallel operation. As an alternative to the method of paralleling on an artificial load I should like to have the author's opinion as to the possibility of inserting between the running and the incoming machines resistances or reactances which could be cut out in one or more steps. The same arrangement could also be employed to prevent the surge when paralleling the induction machine in the manner referred to. The author refers to the impossibility of appreciably altering the load distribution between synchronous machines running in parallel by varying their field excitation; but as the load which a machine takes up depends upon its relative phase displacement it would therefore be interesting to know to what extent this displacement may be controlled by altering the excitation of the motor half of the machine. Control of the phase displacement in this manner would probably be obtained at the expense of a leading current in the line; but this might not always constitute a disadvantage. The operation of pole-slipping imposes very severe conditions upon the field-reversing switch and I should like to know whether any special type of switch is employed for this purpose, as ordinary field-breaking switches are usually quite unsuitable for such strenuous duty.

Frith.

Mr. J. FRITH: The suggestion I am going to make has probably occurred to every engineer present, and been rejected as foolish. Would not many of the difficulties be overcome or simplified by connecting the two machines with a friction clutch instead of a rigid coupling? Starting-up would be easy; each machine would be started as a motor and gradually brought together with the friction clutch. In synchronizing two stations we must have either that arrangement or the movable stator, or the adjustability provided by using a phase advancer.

Peck.

Mr. J. S. PECK: I should like to suggest that the author includes in his paper a table giving the possible speeds for frequency changers when used in connection with the different frequencies in most common use. There is a well-known type of machine which can be used as a frequency changer, and while its use for this purpose may not be commercially feasible, it is most interesting from a theoretical point of view to consider this machine as a frequency changer. The machine to which I refer is the motor converter. Fig. B may represent an induction motor and a rotary converter coupled up to make a motor converter. If the numbers of poles on the two machines are equal, then the frequency on the connections between the two machines will be one-half the frequency of the supply circuit and the following combinations are possible:—

50 periods supplied, continuous current delivered.
50 " " , 25 periods delivered.
50 " " , 25 periods and continuous current delivered.
Continuous current supplied, 50 periods delivered.
" " , 25 " "
" " , 25 and 50 periods delivered.
25 periods supplied, 50 periods delivered.
" " , continuous current delivered.
" " , 50 periods and continuous current delivered.

This shows the flexibility of the machine. If the total input (neglecting losses) is to be supplied at 25 periods, then half the output is obtained from the induction machine acting as a transformer, and the other half from the c.c. machine which is driven as an a.c. generator by the induction machine. The operation under other conditions may be easily worked out. With equal poles on the two machines, the rating of the c.c. machine is only half that of the induction machine, so that the total machine capacity required is 150 per cent, against 200 per cent for a standard type of frequency changer. If a set of this kind is used for changing from 50 to 40 periods, then the rating of the c.c. machine is only 20 per cent of the output required, so that the total machine capacity is 120 per cent as against 200 per cent for the standard type of frequency changer. This looks very hopeful until one determines the speeds and number of poles of the machines. The general objection to an induction machine is its low power factor, but, with the type of machine shown above, the c.c. machine may be over-excited and thus maintain the power factor at a high value. This, however, involves an increase in size for the c.c. machine. If it is not desired to supply continuous current from the set shown in Fig. B, the commutator from the c.c. machine may be omitted, and this machine then becomes a synchronous motor with separate field excitation. With this arrangement it would be possible to wind the rotor of the induction machine for a high voltage, thus, in some cases, making it possible to eliminate the transformer required for stepping up the low voltage of the low-frequency circuit.

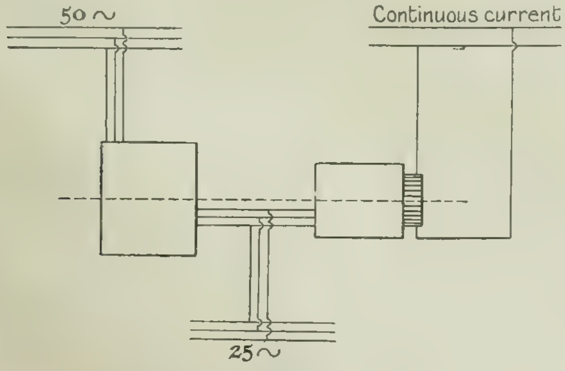

FIG. B.

Professor Field.

Professor A. B. FIELD: The author's discussion of the conditions requisite for paralleling frequency changers on both the high- and low-frequency sides, gives a very lucid explanation of the problems arising; in particular, his demonstration of the necessary phase difference between the incoming machine and its loaded neighbour on, say, the low-frequency side when the high-frequency side has already been paralleled. The device which the author [illegible] the synchroscope has a [illegible], which can be displaced from the [illegible] by an amount depending on the load upon the operating set. With such an indicator, and by [illegible] side of the incoming set it should be possible to pick up fairly quickly the correct motor position for completing the paralleling on the generator side, or vice versa. But, after all, the use of a movable stator appears to be the rational method to adopt, and one would have expected purchasers to specify this system generally, unless there are obstructions of a patent nature in this country. The method has been in use in the United States for many years, and, I believe, has not infrequently been adopted by manufacturers there even when not directly called for by the purchaser, in cases where parallel operation with existing sets has been known to be required. The author passes rather lightly over his second class of machine, in which part of the energy is converted mechanically and part electromagnetically. This, no doubt, is because it has not been used to any great extent. The type has many features of interest, however, and it should be pointed out that its size may be very greatly reduced in comparison with that of a straight synchronous set. Confining our attention to the case in which the outfit consists of two rotating-field machines coupled together, the low-frequency one A—let us for the moment call it the motor—may be an ordinary separately-excited synchronous machine, and the generator B may comprise a similar stator and a polyphase wound rotor fed from the low-frequency side through a potential regulator. We then have the arrangement shown diagrammatically in Fig. C. The maximum mechanical speed of this set, consistent with the frequencies, is the same as for a straight synchronous set, but the number of poles of the generator corresponds to a higher speed, since the field rotates at a speed greater than that of the shaft (if the field be arranged to rotate backwards relatively to the [illegible]. The [illegible] generator stator per kilowatt output depends upon the speed of rotation of its field, not [illegible], in comparison with the straight [illegible] to the field speed, or in the ratio of the difference of frequencies to the higher one; the same applies roughly to the remainder of the set. It will be seen that the advantage in size becomes greatest when the two frequencies are near together, provided that the output is not greater than can be conveniently taken care of with the small number of poles involved for the B machine. For instance, a linking together of 40 and 50 periods would allow us a maximum speed of 600 r.p.m. with the ordinary synchronous outfit; this corresponds to 8 and 10 poles. 600 r.p.m. would also be the maximum mechanical speed available for the arrangement of Fig. C, but while the A machine would retain 8 poles, the B machine would have two, and would gain the electrical advantages of a speed of 3,000 r.p.m. with only the mechanical difficulties of 600 r.p.m. For a transfer of 5,000 kw., the A machine would only be rated at 1,000 kw. plus losses, or less than one-fourth the normal size, while the B stator would be that of a 5,000-kw. 3,000-r.p.m. machine, instead of a 5,000-kw. 600-r.p.m. one.

Professor Field.

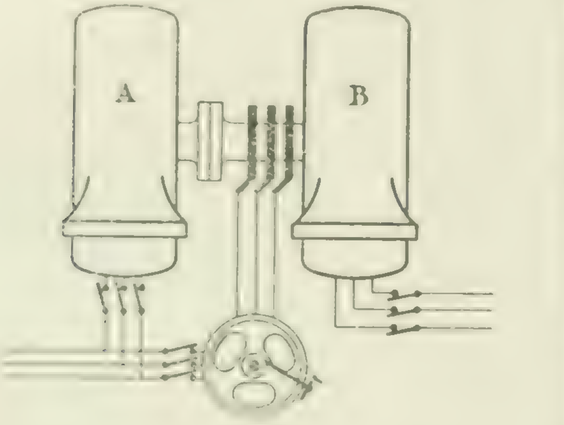

Fig. C.

It becomes necessary, in order to take care of the variations in voltage on each system, to introduce a polyphase induction regulator, and the size of this will depend entirely upon the amount of voltage variations to be provided for, and the reactive drops in the double-wound machine. For instance, in a 30 to 60-period case in mind, the possible variations in voltage on both systems under extreme conditions of load and power factor were estimated to be well taken care of by a ± 15 per cent voltage regulation. As this regulation needed to be effected in respect of the electrical input to the rotor, only, that is, about half the rating of the set; and as the voltage introduced by the regulator could either assist or oppose the supply, the rating of the potential regulator amounted only to some 8 per cent of that of the set. However, the use of this subsidiary piece of apparatus, and the necessity of obtaining part of the excitation by alternating current, are distinct drawbacks to this type of frequency changer. It is of interest to note that with sets of this type we have the two frequency systems tied together, electromechanically through the shaft, and electromagnetically through the high-frequency machine. If we disconnect the low-frequency stator from its busbars, we still have the two systems tied together by the B half, only, of the frequency changer. This tie by itself will not allow any energy to be transmitted from one system to the other, so that it exerts no control on the ratio of frequencies, but it does allow of wattless k.v.a. being transmitted in either direction, as desired. In fact, the B portion of the set operating thus, will transmit energy from the one to the other system only when it is allowed simultaneously to do mechanical work or receive mechanical power. The reason why such a machine floating upon the two systems cannot by itself transfer kilowatts, while the somewhat similar rotary converter floating upon an alternating-current and continuous-current system can do so in either direction, will be apparent upon a little reflexion. It involves the fact that in the present case the flow of power occurs to both the rotor and stator, while the rotor only is concerned in the case of the rotary converter.

Mr. T. H. M. Swinburne: The discussion, so far, would seem to bear chiefly upon the points of design and numerical data, and perhaps one or two remarks outside such points would not be out of place. In the first instance we must suppose that the linking-up of

Mr Swinburne.

nburne.

stations is with an object of national interest—a service of national supply, and general utility. When we remember the confusion in which the whole of the electricity supply of the country now stands on questions of alternating versus continuous currents, different voltages, frequencies, systems of supply, and almost everything else, one is struck with the idea that more uniformity would be desirable. The conclusion arrived at by the author, in the last paragraph of the paper, becomes beyond dispute—something of the kind being absolutely necessary. Again, the author makes out a very strong case for the synchronous type of motor as against the induction type; and, of those mentioned on the first page, it would seem to be a choice of the least evil. It is up to the Institution—perhaps to this Local Section more particularly—to have an established type of machine, and to see that such be used wherever possible, even if legislation be deemed necessary in the national interest. Some progress seems to have been made recently in the commutator type of machine; which might, perhaps, be worth consideration.

Juhlin.

Mr. G. A. Juhlin: In comparing the induction and synchronous types the author has hardly emphasized sufficiently the disadvantages of the former. The question of power factor of the induction machine becomes serious when operating as a generator, due to the fact that, as pointed out in the paper, it is unable to supply any wattless current to the system but on the contrary draws wattless current from it. The importance of this feature will be clearly appreciated by considering a specific case. Assume a station of 7,000 k.v.a. at 80 per cent power factor, of which 5,000 kw. is supplied by the generating plant in the station and 2,000 kw. through a frequency changer from another station: the wattless load required by the system would then be 5,250 k.v.a. and the induction generator would require 920 k.v.a., assuming the power factor of the induction machine to be 91 per cent, which may be taken as an average figure. This would mean that the power factor of the synchronous machines would be 62 per cent and that either the k.v.a. capacity of the station would have to be increased or some form of power factor improvers introduced. In either case extra machinery has to be provided and additional outlay therefore incurred. The variation in frequency due to the slip is also a disadvantage, and the only marked advantage of the induction set is that it forms a flexible link, but it would seem that the difficulties of the synchronous set as a link between large stations have been considerably overestimated. It is interesting to note that the author advocates the use of a movable stator for paralleling purposes. This arrangement undoubtedly provides the safest and at the same time the simplest way of synchronizing large sets. The freedom from any mechanical stresses on the windings is of considerable importance in the case of large high-speed sets. Low-speed generators of low voltage will stand rougher handling than high-speed high-voltage machines, and due consideration should be given to this point in deciding the necessity or otherwise of providing a rocking stator. Many engineers hold that it is unnecessary to provide means for rocking the stator, it being contended that it is perfectly safe to parallel sets with the phase displacements generally met with. It is doubtful, however, whether this is sound practice, as will be apparent when the actual conditions which may be met with are considered. In modern machines it is not uncommon to have a displacement of 40°, and considering a change from 25 to 50 periods we obtain a phase displacement of 120° on the 50-period side. If a machine of small output, as compared with the system to which it is to be connected, is paralleled under such conditions, the stresses on the windings will be considerably greater than if the machine were short-circuited at the terminals. The shock in switching machines out of phase on to a system can of course be reduced by connecting a choking coil in series, thereby reducing the current rush. A special switching arrangement is, however, necessary and would be more complicated than to provide movable stators. As regards the mechanical arrangement, there does not appear to be much difficulty in this connection, and, as pointed out by Professor Field, this scheme has been adopted in America where large sets have been built with the stators movable by means of a small motor mounted on the bedplate.

Mr. Juhlin.

Mr. Townend.

Mr. R. Townend (*in reply*): Professor Walker's remarks are of great interest. There is no doubt that the use of a phase advancer, in conjunction with an induction frequency changer, will give operating characteristics which are on an equality with, and in some respects better than, those of the synchronous set; but in the majority of cases the cost of the former will be higher than that of the latter, and also the attention and maintenance necessary will be slightly greater. The arrangement shown in Fig. A gives a simple way of obtaining a displacement of the poles, but I think there is no doubt that a standard type of machine with salient poles and a movable stator is more desirable and less expensive.

Mr. Ratcliff asks for the efficiency of synchronous frequency changers. The figures will of course depend upon the rating of the set, but a 1,000-kw. frequency changer having a speed of 500 r.p.m. or thereabouts will have an overall efficiency of approximately 89 per cent at full load and 82 per cent at half load. It is quite correct that the characteristics of the transmission line, and the general lay-out of the cable system, may in some cases determine whether the frequency changer should be installed in the high or the low-frequency station, but when the line characteristics are of no importance in this respect, it is usually immaterial—from the performance point of view—in which station the set is installed. It is usually not practicable to run synchronous and induction frequency changers in parallel, but in some cases this may be done, e.g. 25- and 60-period systems could be linked up by means of a synchronous set running at 214 r.p.m., and by an induction set operating at 720 r.p.m. When two such sets are running in parallel, the induction set will always carry the load, which will give a motor slip of 4 per cent. There is no great difficulty in building machines with movable stators, and this has been satisfactorily done with machines having a capacity of at least 5,000 k.v.a. With large machines it is advisable to move the stator by means of a motor controlled from the switchboard. The shock caused by paralleling unloaded and loaded synchronous sets could be reduced by inserting resistances or reactances between the loaded and unloaded machines, but this of course involves additional apparatus and is not as simple as using the movable stator. It is possible to obtain a variation in the load distribution between two synchronous sets running in parallel by varying the motor excitation, but the variation will be small, usually only about 10 per cent of full load. There is no difficulty in making a field switch for reversing the field excitation: it should be mechanically strong and fitted with an efficient discharge resistance.

Mr. Frith proposes the adoption of a friction clutch between the two machines of a synchronous set in order to simplify the paralleling of two stations. This would certainly be the case if only one set was to be run, but if a second set had to be paralleled with it, it would be necessary to give the requisite angular displacement between the motor and generator of the incoming set before closing the clutch, in order to make this set take its share of the load. To do this would of course be impracticable.

As suggested by Mr. Peck, I have added to the paper a table (Appendix, page 204) giving the possible operating speeds for synchronous frequency changers used in connection with the more usually adopted frequencies. The machine shown in Fig. B is certainly interesting, although, as Mr. Peck points out, it is very doubtful if it is of any commercial value. It is of course a modification of the second type given in the paper and has the disadvantages mentioned in connection with that type.

Professor Field has given careful consideration to the second type of frequency changer. There is no doubt that machines of this type may be considerably smaller than those of the third type, but, as he points out, the necessity for an induction regulator and for obtaining part of the excitation by alternating current is a distinct disadvantage. It is also necessary to collect the greater proportion of the power from slip-rings, and in the case of high-voltage machines this is very undesirable.

Mr. Swinburne wishes the Institution to standardize the type of frequency changer to be used for linking-up purposes. I do not consider that any one type is sufficient to meet the requirements of every case, and the only satisfactory way is to adopt the type of machine most suitable for the case under consideration. A frequency changer having an alternating-current commutator motor instead of an induction or synchronous motor would enable a variable ratio of frequency transformation to be obtained, but the set would not be reversible.

I am quite in agreement with Mr. Juhlin as to the disadvantages of the induction generator and the necessity of a movable stator in the case of large high-voltage machines.

DISCUSSION ON

"PRINCIPLES INVOLVED IN COMPUTING THE DEPRECIATION OF PLANT." *

YORKSHIRE LOCAL SECTION, 10 JANUARY, 1917.

sfield.

Mr. J. J. H. STANSFIELD: Although the paper sets out the principles involved in computing depreciation and seeks to apply those principles to practical purposes it does not take into account the difficulties which must be met and overcome by the accountant, and also by the business man who has to make the undertaking a success. I have read with care the authors' definition of the respective functions of the engineer, the financier, and the accountant, and I consider it would be much the same thing if it read like this:

> The function of the engineer is to direct what sums should be annually set aside for depreciation and determine what methods should be adopted.
>
> The function of the financier is to find such money as is required and invest the sinking fund, and
>
> The function of the accountant is to do what he is told and not to hide his light under a bushel.

Accountants have opportunities from time to time of observing the methods of those in supreme authority and of appreciating the reasons for the somewhat rough-and-ready methods sometimes adopted. In considering depreciation, we must take into account that the primary necessity is to obtain business and that we are forced to deal with depreciation according to the results of the year's working. In practice we find that municipal councillors, and shareholders and directors, do not concern themselves very much with rates or methods of depreciation, and though engineers may direct and accountants may obey, they will both in the end have to adopt methods which are as little complicated as possible, taking into account the desires of the directors, pressed by shareholders and others who are anxious to know the result of the year's working. Both must remember that, after all, the powers-that-be will depreciate just so much or just so little as they please. But even managers and directors cannot do just what they like. In the first place, there is the innate conservatism of the Briton. Then there are the difficulties of obtaining business due to competition. On page 141 the paper sets out substantially the various methods of treating the provision for depreciation. The maintenance method—considered by the authors to be unsatisfactory—is the policy pursued by our railway companies with their enormous capitals and plants and, although perhaps not theoretically sound, there must be something in it. I agree with the authors in objecting to the reducing balance method, because during the earlier years the plant will not earn so much as in later years, and profits would not be such as to provide a sufficient surplus for depreciation. With regard to the sinking fund method—the one advised in the paper—I will take the alleged objections to that method mentioned on page 148. I cannot see that the fact that the straight line method is usually employed is not in itself an important reason. Broadly speaking, I think the reasons may be stated to be based on practice, even if they are theoretically imperfect. In the first place, the sinking fund method requires very elaborate book-keeping if it is to be consistently adhered to, because the life of each important piece of plant would have to be dealt with separately. Thus the accountancy staff would necessarily be increased. As regards the sinking fund method being objected to because it would be unfair either to the buyer or seller, I agree it would be absurd. After all, when it comes to actual practice, is not the sinking fund method itself an estimate? And for these reasons: First, the life of the new plant is unknown. The best that anyone can do is to give an estimate of its life based on experience of old plant of a similar character. Secondly, it cannot be stated in advance what the units of work will be. Thirdly, plant is made up of several parts with different lives. Lastly, there is the great diversity in the life of plant (even in the case of machines purchased from the same manufacturer and at the same time). The sinking fund method has its definite uses. It may safely be employed in the repayment of money—either by equated or irregular payments. In such cases there is a definite period within which it must be repaid. But it has very practical objections when we are dealing with plant the life of which can only be estimated and where we can only depreciate in accordance with the amount of profits we make. To use a sinking fund with absolute accuracy, the engineer would have to be both an actuary and a prophet, and in addition he would have to guarantee the profits. No! where the powers-that-be can be persuaded to consider that theory has anything whatever to do with depreciation, the usual method will be to—

Mr. Stansfield.

> Take the total of each class of assets as shown in the balance sheet at the end of the year;
>
> Determine the rate of depreciation that each total should bear;
>
> See what profits there are;
>
> Consider what amount is required to help the rates, or what rate of dividend should be paid to the shareholders to satisfy them and attract additional capital;
>
> Find the total amount of the depreciation which should theoretically be charged against the profits;
>
> And, finally, transfer to the depreciation fund part of those profits.

Summarized, the points I wish to make are as follows:—

(1) A rigid method cannot be chosen because the factors are uncertain. The life of the plant is unknown and although the history of other plant is helpful it can only be approximately so.

(2) Any method of depreciation chosen must be a practical one, without complication or intricate accountancy.

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* Paper by Messrs. F. Gill and W. W. Cook (see page 137).

Mr. Stansfield.

(c) Plant cannot be bought without money. We must pay interest or dividend on that money out of a revenue which is often fluctuating and the profits available for depreciation are influenced by the competition we have to meet. Obviously the prices we charge must not ignore depreciation. That would be fatal to success. But that fact does not prevent us from using methods which may be imperfect, as has been proved over and over again by the many successful undertakings we see around us.

Mr. Whitaker.

Mr. G. [illegible] Whitaker: The authors seem to take maintenance as a standing charge, however much the plant may depreciate. I have found in actual practice, however, that the maintenance charge increases year by year. I must admit that I have adopted the straight line method extensively. In local government we are restricted by the Local Government Board to fixed terms of years within which to repay loans raised. When electrical undertakings were started, the Local Government Board made the mistake of allowing periods which were too long. Latterly these periods have been reduced and varying terms of years for the various classes of plant (based on life) are now allowed. Local authorities differ from companies in that they have to repay their capital, whereas the companies have a stationary or increasing share capital. I think Mr. Stansfield has "touched the spot," as it were, when he says that the question is one of expediency. If there are no profits, then the provision for depreciation must be abandoned. The whole matter seems to me to be this: that companies have their shareholders, and I have my ratepayers, to consider. In dealing with the improvements fund, the authors have raised a new point, so far as I am concerned. Where the plant is subject to obsolescence the provision of an improvements fund would place the undertaking in a position to take advantage of any improved methods.

Mr. Mitchell.

Mr. J. Mitchell: I am not an expert in these matters, but perhaps there are one or two points it might be of interest to touch upon. Mr. Whitaker mentioned one, namely, that capital borrowed by local authorities has to be repaid by sinking fund. He also referred to the improvements fund. It seems to me that if the sinking fund period be correct—and it must be remembered that such period is determined for a local authority by a higher authority, i.e. either by Parliament or by a Government Department—nothing more need be done in the way of providing for depreciation or improvements because the repayment of the debt within the period co-terminous with the life of the asset is all that is necessary. After a loan has been paid off a fresh power to borrow can be obtained for the renewal of the plant, if desired. If at any time it be found necessary to put moneys aside (other than for the sinking fund) for either the renewal or improvement of the plant, then it is proof that the sinking fund period is too long, and a local authority would [illegible] to speed up the sinking fund payments. The sinking fund (or loan period) allowed for repayment of debt are maximum periods and can be [illegible] with by a local authority if it considers it necessary to do so. I gather from the paper that what is required is to try and agree if possible upon a correct method of ascertaining what charges should be made each year upon the income of an undertaking in order that each year be debited with its proper share of the cost of the plant, having regard to its economic life, rather than to leave the question to be settled by expediency or anything of that sort.

Mr. R. [illegible]: A recent experience of mine may be of interest. A wholesale clothier had, before the War, plant worth, say, £10,000 (this figure is hypothetical), which was sufficient for all his requirements. When the demand came for clothing for the soldiers he enlarged his place at a cost of, say, £10,000. What he put to me was this: How would I value the plant when this temporary demand is over? Also, what reduction could he claim in regard to income tax, and how was provision to be made for the depreciation which would result on a speedy realization of the plant when it was no longer required? This is how I considered the question. Suppose that he has spent £10,000 and that the War lasts four years, also that he has made an additional £2,000 per annum owing to the War. If we assume income tax to be at 2s. 6d. in the £, in four years he would have paid £1,000 income tax and his extra profits would have been reduced from £8,000 to £7,000. Then if he were to ask me to sell his machinery by auction and he gets £5,000 for what originally cost £10,000, the residue of his profits in four years would be £2,000, unless he provides for depreciation before he pays his income tax. But I suppose that the income tax commissioners would be very loath to allow such depreciation on that plant as would enable him to do what I have indicated.

Mr. W. Lang: Mr. Stansfield's and Mr. Whitaker's comment, that depreciation is a matter of expediency, is correct only to a certain extent. Depreciation is a necessity and cannot be neglected. It is possible to make use of it in good years, and also in bad years—to help an undertaking, say, over a very difficult year, or to "level up" a good year—but it would not be wise to admit more than that. We cannot fix our charges for any commodity we are producing, whether it be electric power or a manufactured article, without knowing what we are going to allow for depreciation. There are very many factors affecting the question of depreciation which are not mentioned in the paper; for instance, the rise and fall of the bank rate. I think that is an important item in connection with the value of depreciation in very large undertakings where money is paid into a depreciation sinking fund and is not available for very urgent work such as renewals or extension work.

Mr. J. E. Storr: I think perhaps the paper is more idealistic than practical as things stand to-day, in view of the amount of work necessary in compiling the numerous returns which would have to be prepared for the complicated system of book-keeping involved. There are one or two points on which I should like fuller information. On page 138 in the [illegible] paragraph it is stated that "the purpose for which they (the annual charges) are required is to enable the engineer by their means to select plant wisely, and so to plan economically." Are they not far more important in connection with the charges to be made for the commodity to be sold by the undertaking, or the cost of production? On page 138 depreciation is included in the annual charges and on page 139 deprerr.

ciation is defined as including "improvements," or, as we should hitherto have said, "the replacement of obsolete plant." I think the inclusion should be distinctly qualified; that is, that it does not apply to all plant, because at least one-third of an electricity supply authority's assets is not subject to obsolescence. To include such a charge on all plant is of course unnecessarily inflating the price of the commodity where improvements are not called for. Such things as tramway lines or cables would not be improved. They would wear out and be replaced by other lengths. I appreciate the point that to select items for different kinds of treatment would still further complicate the keeping of accounts, but I think the point ought to be borne in mind. Then I think consideration should also be given to the possibility of carrying out improvements in a more certain way by transferring the cost to the replacing article. That is to say, if we are installing a turbine which will put other plant out of commission it should be able to carry the old plant on its back.

lton. Mr. A. Walton: Speaking from an accountant's point of view, I am afraid that if the authors tried to explain this elaborate sinking fund system to those with whom we have to deal they would find it difficult to get it enforced. Business men will listen to what we have got to say, but it is useless to suggest anything elaborate. When an accountant meets his clients, he has therefore to confine his remarks on the subject of depreciation principally to two main lines. First of all there is the straight line method; and secondly, the reducing balance method. It is only in that way one can get the bulk of the business people to understand really the true effect of depreciation. As accountants we always recommend the reducing balance method. It is quite true that in the first year this results in a larger amount of depreciation than in later years, but the amount for repairs is very small. If we take it over several years we shall find that the amount of depreciation written off under this method plus the cost of repairs will be almost the same sum year after year. In any case the figure will be more constant. That is why this method recommends itself to accountants more than the sinking fund method. A previous speaker pointed out that if we adopt the sinking fund method, it means we must have an elaborate system of book-keeping, and where we are to get the men to carry it out I do not know. A few years ago there was a very big arbitration when we heard a great deal about depreciation. That was at the time when the Government took over the telephone system, and I think it was Sir William Plender who introduced the sinking fund method of depreciation. It was good in theory, but not in practice. What happened was this. The arbitrator adopted the "5 per cent clean cut." He was not going to bother with any elaborate calculations. That was the basis. Generally speaking, that will be found to be the attitude of business men. At the end the result will be all right. Suppose we have plant of value £100 and we depreciate it at the rate of 5 per cent per annum for, say, 5 years. That roughly is £25. We sell the plant for £10, making a total of £35. We have lost £65 on our plant, and this amount can be written off if desired as extra depreciation, and, compared with the total value of plant, the rate would not be appreciably affected. For income tax purposes this £65 extra depreciation would be allowed as a proper deduction under the head of obsolescence. I should like to refer to the point raised by Mr. Levitt with regard to the wholesale clothier. Supposing a man puts down £10,000 of new plant and machinery, and in four years the trade for which this plant was installed is gone, he must have allowed as an expense this cost of £10,000. What he does is this: First of all he has got to satisfy the income tax authorities that he has put down this plant specially for the purpose of fulfilling the war contracts placed with him by the Government. When he satisfies them on this point, he must then satisfy them that the particular plant depreciates fairly rapidly. On a sewing machine, ordinarily one gets 7½ per cent depreciation, but in these days with extra hours worked and because of other factors, 15 per cent may be obtained. Therefore one claims 15 per cent. Depreciation is reckoned at this rate until we sell our plant and machinery and claim for any value left in the books in the way I have indicated. In that way there is no loss.

Mr. Walton.

Mr. W. M. Selvey: The authors' arguments appear to me to be something like this. In a company whose stock or shares are equivalent to a gilt-edged security, every method, however theoretical, which can help to define accurately the exact financial position of that concern should be adopted, and if possible nothing should be left over either to be treated as a matter of opinion or as a matter of "use and wont." Other speakers have dealt with what may be termed a more speculative class of business, and perhaps the bulk of the business of the country is yet of that nature. A man in a speculative business does not want to know exactly what his capital is. What he is interested in is the amount he turns over, and what profit he makes on it. His real capital can vary. While he does not want to know what he is worth as long as his business is a private company, it becomes a matter of acute interest when he wants to turn his business into a limited liability company. Then the capital written down is generally a great deal more than he ever thought he was worth. It seems to me when dealing with a company which is at the stage of becoming a large, sound limited liability company, there is a certain sense of value about the concern which cannot be called capital, and yet is of the nature of capital. Probably this is what is often vaguely described as goodwill. The argument of some speakers which, I take it, is intended to apply to a speculative business having a large element of goodwill in its actual value, is that it is not only legitimate but necessary to draw on that goodwill in the sense of not placing to depreciation a certain amount of the gross profits in any particular year because of the necessity of keeping up the face value of the actual shareholders' capital by maintaining the usual dividend. The equivalent of this goodwill when the company has attained a settled position should be a reserve fund. It should not be necessary therefore for a well-established company to vary its depreciation scheme for any particular year, because the reserve fund should be available to level up the financial operations of the company. It appears to me, then, that the condition of the reserve fund added to a knowledge that an accurate depreciation fund method, as recommended by the authors, should show the financial position of the company very accurately. This is the impression which has been made on me by the remarks of the various financial authorities. With regard to the divergence of opinion Mr. Selvey.

Mr. [illegible] among them: I think it can be explained by considering which kind of company they are thinking of. These I have tried to suggest are three. First, a speculative company, which is sound, but part of whose value is goodwill; second, this company in the next stage of progress, when the goodwill is written off and is replaced by a reserve fund; third, when the company has become so large that it really operates under the insurance company conditions and must make a steady dividend by the magnitude of its operations. At the third stage especially, the most theoretical method available should be applied to determine its financial position. Perhaps the authors will inform me in their reply whether I have correctly understood the matter.

Mr. [illegible] Mr. W. H. [illegible] (communicated): In all the engineering and manufacturing concerns with which I am professionally associated, depreciation by reducing or diminishing balances is used, and I do not know of a single instance in which the so-called straight line method is utilized. Hence the trenchant criticisms of this method fall to the ground, and the authors should re-draft their paper, comparing the sinking fund method with the reducing balance method. In my experience, the life of engineering plant is considerably varied by excessive use, in addition to improvements, and every case should be considered on its merits. I have frequently advised an initial depreciation of 25 to 33⅓ per cent immediately on the installation of plant, as the purchase price of new machines includes the profit and selling charges of the vendors, and afterwards depreciation on the diminishing balances, based on the estimated life of the machine, with extra allowance for excessive use, double and treble shifts; and I have invariably recommended that all additions to the machinery by way of improvements should be charged to repairs and renewals and not to capital. The majority of engineers, in taking out their costs for quotations, include a round sum per hour for the use of the machine and for labour, but in my opinion this is frequently underestimated and the cost of the use of the machine per hour should be entirely separate from the cost of labour per hour in connection therewith. In my opinion many firms do not write off sufficient depreciation, and are consequently eventually left with an out-of-date plant, and the various engineering federations should combine to put pressure on the Inland Revenue authorities to secure the allowance of proper and reasonable depreciation on plant, instead of the 5 per cent depreciation at present allowed, which is in most instances totally insufficient.

Mr. [illegible] Mr. H. F. [illegible] (communicated): The authors' paper opens out many controversial points and I hope that engineers in charge of both company and municipal undertakings will discuss matters from their own particular standpoints. I agree that no standard rates for depreciation can be devised to serve all conditions. For instance, if, as the authors say, the function of the financier is to provide information regarding "the amount of money available," is it intended where such amount is small for a specific undertaking to restrict the amount set aside for depreciation? Although it is the function of the accountant to provide accurate records, these are usually based on "information supplied" rather than on the "decisions arrived at." The question of alternative design and specification for plant is very important, as obviously there is a point where first cost ceases to be as important as annual charges. It is regrettable that, whereas "works costs" are regularly published for nearly all undertakings, the total costs including capital charges are invariably suppressed. Under "lives—physical and economic" it does not appear to be a sound business policy to charge new plant with the making of money to repay the balance of capital on old plant taken out of commission. All engineers appear to agree that a special fund is essential. To call this fund the improvements fund is a debatable point. This fund is apparently for the development of the business, made up of contributions taken from the net profits, in other words a reserve fund for use as circumstances render advisable. The latter name appears to me to be better than the former. With regard to the authors' statement that in the straight line method of providing sinking fund, it is the general practice to credit the revenue account with the earned interest, this is not so in municipal undertakings, which invariably adopt the straight line method. I cannot agree that small parts such as dynamo brushes and firebars which have a comparatively short life should be charged to renewals. Were such the policy, the works costs, including maintenance, would be very low and would not show the true state of affairs. I advocate that where parts of running plant wear out within five years, they should be charged against maintenance, and if renewals are required after that life, then these items should be charged to renewals. Under "assessment of profits" I think no hard-and-fast rule can be laid down to allow for depreciation and obsolescence, as so much depends on local circumstances, and in municipalities on the period of the loan; for where the period is a short one it does not always seem desirable to supplement the sinking fund by a depreciation fund, assuming that the annual sum so set aside is sufficient to cover depreciation. I cordially agree with the authors' conclusions that all estimates require revision from time to time, and this has been emphasized in a striking manner, especially in money values, during the war.

(The AUTHORS' reply to the discussion will be found on page 226.)

MANCHESTER LOCAL SECTION, 16 JANUARY, 1917.

Mr. [illegible] Mr. J. E. [illegible]: Members generally will agree with the definition of the respective functions of the engineer, [illegible] upon the need for the closest co-operation. Within the [illegible] the late Sir William [illegible] where Sir John Snell was associated with an eminent accountant. I feel sure that the co-operation resulted in great benefit to those undertakings. But when all has been said on this point it remains true that the engineer has to bear the brunt of the correctness or otherwise of [illegible] upon him at the start to estimate the factors which determine it, namely, the first cost and the lives of various portions of earce. the plant. The authors have made it perfectly clear what they mean by the term "depreciation." They resolve it into two component parts, "renewals" and "improvements." The first of these, viz. renewals, makes provision for the expiring capital outlay, which is provided for in the case of local authorities by means of the statutory sinking fund in connection with electricity undertakings. The term "improvements" is perhaps better known to electrical engineers under the name of obsolescence. I do not think all engineers are fully alive to the necessity of making provision against the possibility of having to scrap portions of the plant before the physical life is at an end. It must be emphasized that depreciation is as much a working charge as fuel, and it must be settled on some well-defined basis, not dependent upon the amount which a company desires to pay in dividends or a local authority to allocate to the relief of the rates. Contrary to the opinion expressed by the authors, I think there is a fair measure of agreement among engineers with regard to the question of the life of plant, upon which of course, the "renewals" chiefly depend; but the trouble lies in the fact that the recommendations and opinions of experts are very often ignored. When we come to the question of obsolescence or improvements we get into the realm of speculation, and there is a divergence of opinion as to the percentage allowance for residual values. It is almost impossible at the present time correctly to forecast future progress or when the scrapping policy will become desirable; therefore, while from the strictly logical and scientific point of view I do not for a moment quarrel with the method followed by the authors, I would in all seriousness ask them whether they really consider it to be necessary in practice to make two sets of elaborate calculations. I suggest that one set would reasonably satisfy all practical requirements. It would be based upon the life of the plant, either physical or economic. If the former basis were adopted it would be prudent to build up a general reserve fund to a substantial amount which, of course, would depend entirely upon local conditions, in order to provide for the possibility of having to scrap a portion of the plant before the physical life comes to an end. Next, with regard to the practice of the Local Government Board in granting loans, going back 10 or 12 years we find the practice was to allow fairly long periods for repayment—periods which were undoubtedly in excess of the economic lives of portions of the plant, if not in excess of the physical lives. But since 1906 the Board seem to have leaned on the other side and the periods are unduly short. I am not clear whether the Board now intend to cover both physical and economic lives; indeed it is open to doubt whether the new policy is based upon any very definite ideas at all. Possibly it is the result of what may be termed "the swing of the pendulum."

The bulk of the paper deals with the question of which is the correct method to adopt, namely, the sinking fund method or the straight line method. The former is adopted by municipalities, and I think a very strong case for it has been put forward in the paper. As to the straight line method of treating depreciation, I understand that the authors have not met with any pronounced advocates of it. The exceptionally clear and interesting tables and figures given in the paper put the case for the sinking fund very strongly. The choice between the two methods becomes more important when it is a question of making a valuation of the plant as shown in Tables 8 and 9. On page 139 the authors unduly, I think, stress the difficulties of carrying out what I may term a modernization of existing plant. In these days many of us have been compelled to adopt a big scrapping policy; schemes are being held up and engineers have to modernize existing stations so as to increase outputs, and difficulties arise when no provision has been made for an improvements fund. The difficulties must not be exaggerated. So far as local authorities are concerned, the practice is well established. The Local Government Board will grant borrowing powers corresponding to the full value of the new plant required, less the amount outstanding on the old plant. For the period the old plant has still to run, the undertaking carries a double burden—the annual charge on the old plant and the annual charge on the new plant—obviously every engineer in deciding on the policy of scrapping a certain amount of plant will have to take all those facts into consideration. At the bottom of page 139, column 1, the authors say: "If this course were adopted new capital would not be represented by assets." I do not follow the meaning of the word "new" before capital. In a note on page 138 they say that "the expression 'first cost' is intended to mean any or all of the following, as the context requires." Then the last clause is, "The estimated construction cost to reproduce the plant new." I do not see, however, that any application of that meaning of the expression "first cost" appears in the paper. It must be borne in mind that the cost of reproducing plant is not necessarily the same figure as the original cost. The authors are right in making a strong point of the fact that the life of the plant must be reckoned by the work done and is not merely a question of years. That is brought home to many of us every day. In many electrical undertakings the load factor is going up and is likely to increase still further in the future, and that must be taken into account in estimating the economic life of the plant. I do not agree with the authors that the maintenance costs may be considered not to increase with the age of plant. There is no mention in the paper as to the wisdom or otherwise of providing in addition to the fund for expiring capital outlay a further fund for the acquisition of new plant without recourse to the raising of new capital—commonly known as the double provision basis. I take it the authors disagree with such a policy. With regard to those electrical undertakings which are now compelled to contribute certain sums annually by way of relief of rates, I express the opinion that in the event of this policy being abolished the whole of the benefit accruing therefrom should not go to the consumer. The aim of all undertakings should be self-capitalization, spread over a cycle of, say, 40 to 50 years.

Mr. Pearce.

Mr. Beckett.

Mr. J. BECKETT: In the solution of the problem which we have to discuss, the first essential is to find out the facts if that is possible. Failing that, an approximately accurate basis is desirable, and in fact must be adopted, but until the facts can be definitely ascertained, divergent opinions are to be neither deprecated nor deplored. They are rather a sign of vitality. But over and above individual differences of opinion, we are in practice always oscillating between physical necessity and financial expe-

Mr. [illegible] [illegible] actual present needs and available means. On page [illegible] it is stated, with reference to exhausted plant, that "it may be argued that the cost of making them (the changes) should be defrayed by new capital; but this is not always available. In this matter the question is, [illegible] principle. We are not discussing expedients. The authors suggest that it should be a part of the annual charges. Here we begin to part company. I submit that it is no part of the annual charges in respect of plant. It may be prudent to make provision for it by way of reserve if there is surplus revenue available for that purpose, but it is certainly not true accounting to charge against the plant for any period more than has been taken out of the plant within that period in earning the revenue. Who can fix the charges in advance upon any sort of scientific principle? Who can go into a power house to-night and mark out the parts which will be superseded or become antiquated or obsolete or need replacement in 5, 15 or 25 years? The proposition is clearly indefensible. The necessity for the charge, too, depends very much upon the state of development of the plant and machinery. Is not this the true principle, that plant may be discarded and replaced by more economical plant out of capital when the result of so doing upon the revenue account is a positive financial advantage to the undertaking? Until that point is reached, no engineer would, I venture to say, recommend a change to new plant or a renewal or improvement of the old. Moreover, local authorities cannot give effect to the proposal of the authors, for they have to submit to the limitations and restrictions imposed by the Electric Lighting (Clauses) Act, 1899, by which they are restricted to a reserve fund and a surplus revenue of 5 per cent upon the capital outlay. This brings us to definitions of which wise men have fought shy. That definition on page 137 is very interesting. The word "depreciation" has been loosely employed, and has been given various meanings. I find myself unable to agree with the authors, and will venture upon another definition of depreciation. It may be defined as: The charge against revenue of any given period of that proportion of the cost of production during that period which represents the consequent fall in value due to wear and tear of the producing machinery and plant; or as the repayment to capital out of the revenue earned during a given period of such proportion of the original outlay as has been absorbed or consumed in earning such revenue. More briefly and in other words, it is the capital restoration charge. A banker's practice affords a good illustration in one respect. He knows the cost of his investments. In his case the market value of these investments can be definitely ascertained periodically. If they fall in value he writes off the amount of the fall. In the same way it is the duty of the engineer to ascertain the value of the plant at the end of a given period due to wear and tear. Depreciation, as such, is not, as the authors say, a financial operation; it is clearly a physical process having no necessary relation whatever to finance. It is, of course, expressed in terms of finance, but an engineer put into a power house for the purpose of determining the depreciation of the plant can well proceed in terms of percentages without any reference to finance whatever. Apart from its nature, depreciation has no relation whatever to improvements. The fall in value arising from obsolescence, supersession, antiquation, or the introduction of improved machinery cannot be dealt with along mathematical lines, or by any rule or regulation. These things are distinct from depreciation of fixed capital, and must be dealt with by other means. Therefore I am at issue directly with the definition of depreciation given by the authors. The primary object of depreciation is the preservation of the original capital, and the measure of the annual charge is the amount of capital annually consumed by the production of the year. Nor has depreciation any relation to the return on capital outlay, contrary to what is stated several times in the paper. Let us suppose that we have a period of trade depression and losses have to be incurred over a period of several years—would that fact touch the question of depreciation? Would the process of depreciation suspend itself in the meantime? No, the process goes on, profit or no profit. If the authors had kept that fact in mind, it would have saved them the necessity of many calculations in the paper which needlessly take account of the return on capital, because the return on capital has nothing whatever to do with the question of depreciation.

Coming to another subject, it is stated on page 143 that "the depreciation fund is not required until the end of the life," and we are asked what is to be done with the money annually set aside meanwhile. If we have an accumulating depreciating fund, and can fix the minimum rate of interest for the accumulating period, we are, I think, on the highway to the solution of the problem submitted to us. Meanwhile that fund, wherever it is, is of the nature of capital, either in a fixed or liquid state, waiting its true function of restoration. I cannot imagine that anyone here, or elsewhere, will defend what is called the straight line method, and for this reason, that the method extracts from revenue the total amount of capital in the name of depreciation, regardless of interest which properly belongs to the depreciation fund. By an accumulating method one likewise gets a flat rate of charge over the whole period of the estimated life, but the fund requires and obtains interest earned, therefore I find myself in agreement with the authors on the question of the character of the fund to be employed for depreciation. The purpose of the sinking fund—I am speaking now from the point of view of municipal accounts—is fundamentally different from that of the depreciation fund. It is the work of the sinking fund to provide capital. By its means the capital of a local authority is acquired. Hence the local authority with a true depreciation fund, plus a sinking fund, carries a double burden. First, for the restoration of the capital, and second, for the acquisition of capital; and if we are going to insist upon both, we shall handicap enormously the initiation of any municipal scheme when compared with private concerns. Pursuing our quest of definitions, what is capital? Adam Smith in his "Wealth of Nations" defines it in these terms: "Whatever a person saves from his revenue he adds to his capital; hence capital increases by parsimony and diminishes by prodigality. Capital can be increased only by what is saved from annual revenue." He adds: "Stock which is lent at interest is always considered capital by the lender." This in brief, without proceeding with any further demonstration. What, then, is net revenue? We shall get at it more readily by defining what it is not. In Adam Smith's terms: "The whole expense of maintaining fixed capital is necessarily excluded from net revenue. Neither the materials necessary for supporting useful machines and instruments of trade, profitable buildings, etc., nor the produce of labour necessary for fashioning those materials into proper form can ever make any part of net revenue." Certainly items of charges against revenue do not include any charge for what the authors define as improvements. Let us next consider maintenance. It is described on page 138 under the head annual charges as "the cost of keeping the plant in as good condition as is desirable, but not of renewing it." This arbitrary dictum is repeated on page 153; but where are the frontiers between maintenance and renewals? For example, take the wearing parts of an engine. We replace a worn-out brass step, or a piston ring, or re-bore a cylinder, and what have we then done? I submit that we have done two things: we have both repaired and renewed. Will anyone attempt to draw the line between these two things? On page 139 it is assumed that the cost of maintenance is constant each year. Now with depreciation fixed upon the first cost and the maintenance constant and taken for granted that it will not increase with age, in what part of this scheme is provision made for the items which combine repairs and renewals to which I have referred? In dealing with the subject of average life and equated life, the authors seem to have got somewhat confused. I have never heard before that these two things were in fact different. On page 150 they say that "there is a great danger if the difference between average and equated lives is not appreciated," and again, "for a complex plant, use of the average life will result in inadequate provision, because the equated life is always shorter than the average life." Now, how can this be, if as stated on page 143 "the depreciation fund is not required until the end of the life," and on page 152 "it is clear that an equated life arranged for all the plant provides money for the renewal of every part"? In this connection, Table 10 is interesting to me. The equation of the three items of £100 for 10, 5, and 2 years respectively, seems to be 5·66 years and not 3·75 years. In conclusion I will quote a relevant resolution passed at a special general meeting of the Incorporated Municipal Electrical Association in 1902: "That in the opinion of this Association, electricity supply undertakings having to be maintained in a thorough state of efficiency out of revenue, no depreciation or further writing off of capital is necessary when the period allowed for repayment of loans is not greater than 30 years, as the equated life of the plant exceeds that period." With that dictum I heartily concur.

Alderman W. WALKER: I dissent from the authors' proposition that there should be two depreciation funds. I cannot see any necessity for it. If we decide that we are not going to run our plant for the whole of its physical life but for a shorter period which we term the economic life, the amount set apart for the sinking fund should be something which at the end of such life fulfils the object for which it was created. I cannot understand why the authors think it necessary to consider any other factor than the actual life of the plant. There is another matter I should like the authors to explain because I do not agree with them. It is the question of residual values. On page 140 they allow 2 per cent residual value for the physical life and 13 per cent for the economic life. The economic life is the period after which we are justified in scrapping the plant, and in my opinion we have no right to estimate for more than scrapping value. In 95 per cent of cases it is looked upon as a stroke of luck if we find a customer who can fit this plant into some requirement which he has at the moment. The scrap value at the end of the economic life will practically be no greater or no less than the scrap value at the end of the physical life if it is running plant; and if it be the distributing system, then the value of the recovered copper ought to be assumed as the same for both periods. Again, it is well known, especially in connection with batteries, that maintenance agreements are made between makers and purchasers. Do the authors recommend that the annual payment should be treated as insurance, or do they think it ought to be debited to the renewals account? Carefully as this paper has been prepared, sound as their system may appear, still much depends on estimates, and these are disturbing elements. We have always to determine what is to be the standard of maintenance and I find opinions, or at any rate practices, differ very greatly as to the amount which should be charged. A plant which has been allowed to suffer in its early years in order that large dividends could be paid will be affected in its later years by that mistake. That is a factor which may upset the original calculations of the economic and physical lives. It must also be borne in mind that plant must not be scrapped simply because its steam consumption is higher than that of other plant. Obviously the most economical plant in the station is run at the highest load factor. The uneconomical plant is only used during the periods of peak load; therefore the percentage of units contributed by it during the year is very small and any gain shown by replacing it would be proportionately small. One has to consider the actual contribution to the total output of the station by the plant which is under discussion. Mr. Pearce has estimated for the Manchester undertaking what he considers to be the true economic lives of the various units, etc. I have here a comparison between those figures and some fixed by Sir William Preece in July 1906 for Bristol. The Manchester figures are the lower. Buildings are taken at 40 years, plant and machinery 20 years, mains and services 20 years, motors 10 years, and so on. These periods are very much shorter than those fixed on former occasions. We decided to establish a renewals suspense account, and to transfer from revenue account each year the amount which, put into the renewals suspense account, would be sufficient to meet the deficiency in the sinking fund as shown by the calculated shorter life of the plant. The total amount paid into that account has been about £344,000, but certain renewals have been paid for and it now stands at £191,000. It is in addition to the reserve fund. But I am strongly of the opinion that the later policy of the Local Government Board in fixing very much shorter periods and dividing up the loans in accordance with the plant on which they are going to be spent, is bringing the sinking fund itself closely approximate to the economic life. Municipalities and local bodies have one difficulty which does not afflict private companies. It very often takes the form of a ratepayers' association, whose greatest asset is its name and which professes to speak in the name of the people, who generally know

Alderman Walker. nothing about it. It is always desirous of raiding any surplus shown in the accounts of the trading departments quite irrespective of the future necessities of the undertaking. I am in favour of sound depreciation, of keeping maintenance charges high, and the amount shown as profit as low as possible. I am speaking now from the public utility point of view, which is the one to be taken when dealing with these necessary undertakings. The Finance Committee of the Manchester Corporation in October 1912 in adopting a policy of rate aid actually decided that the amount should be calculated on the capital expenditure. Now I maintain that a more false principle could not possibly be put forward, because £1,200,000 of our capital borrowed has been repaid and to a large extent the assets which represented it have gone out of commission and have ceased to earn any revenue. Suppose we put 1 per cent on the three millions capital expenditure when in fact we have plant of the value of only one million; it means that we are actually charging 3 per cent against the revenue-earning plant belonging to the undertaking. That is one of the things which will have to be fought keenly by accountants and engineers and by representatives within public bodies. Any amount fixed for rate aid must be upon the outstanding loan debt and not upon the capital expenditure; otherwise it will become a growing charge which will jeopardize the existence of the station in competition with other suppliers. It has also been argued that the municipality ought to pay into its sinking fund the statutory amount, and that in addition it ought to create a renewals account which would enable it to have sufficient capital at the expiration of the economic life to replace the plant without further borrowings. This means that the present generation of users would hand over to the next generation of users a power station free of all cost. It would be grossly unfair if done, but an attempt would defeat itself because it would mean such high charges for current that we should not get consumers and so no funds of any description could be maintained. In connection with Mr. Beckett's question as to the difference between repairs and renewals, I do not think I have ever met with great difficulty on that head. He talked about piston rings, re-lining of bearings, and other repairs. They come under maintenance. They only enable the running plant to continue its output. The question is quite a practical one and we have to deal with it every day.

Dr. Cramp. Dr. W. Cramp (*communicated*): In referring to depreciation as affecting the design of plant the authors speak of annual charges as though they consisted of operating costs alone. But in many cases interest and depreciation are higher than any other annual charge. Thus when the authors say that "first cost is nothing like so important as the annual charges," they are using a false antithesis, since the two are interdependent. The authors' distinction between "physical" and "economic" life is easy to imagine but difficult to realize. A low-speed steam engine for instance may have an almost interminable physical life, and the definition of this life will depend upon what is to be considered as maintenance and what as renewal. The most important factor to consider is the economic life, and this is not a matter which can be determined for any plant once and for all. It must vary from year to year according to the progress made in the art of designing such plants. For instance, if gas turbines become an economic possibility next year, the value of all steam turbines, however modern, would be appreciably affected. Thus in my opinion experts should revise from time to time the economic lives allotted to the various parts of an engineering plant. Fig. 1 is interesting, but, like most of the other figures and tables in the paper, it would be much more useful if the manner of arriving at it had been put into a general form and thus made available for cases involving different numerical values. In connection with this it should be noted that though the authors use the term "rate of interest" it is not treated in the paper as a true rate, but as an annual increment or decrement. Thus if R be the value to which £1 increases in one year, A the annual payment per £100 for return on capital, *n* the number of years, then the present value (£94·86) which is the basis of the examples in the paper is obtained from the general formula

$$V = A\ R - n + R \quad 100 - S - A\ R - 1 \quad . \quad (1)$$

S being the value per cent of the plant at the end of its economic life, which value in my opinion should be taken much lower than the authors take it.

Similarly in Table 1, column D is derived from

$$R = \sqrt{S/p} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where R, is the amount to which £1 decreases in one year, and *p* is the first cost. Column C in the same table is obviously a constant proportion of column D, the ratio being that of the rates of interest corresponding to C and D respectively. The tables and curves of the straight line method seem to me to need no comment. Both the method of calculation and the disadvantages of the system are quite obvious, and I can hardly believe that anyone would support it. The authors seem to me in this case to have erected an anachronism for the sake of knocking it down; nor can I see any justification for, or object in, the repetition of columns of similar figures such as occur in Tables 2 and 3. The method of arriving at the charges in Table 5 is not clear and I should be glad if the authors would explain it further. The general formula appropriate to column D in Table 6 is:

$$\text{Depreciation} = V(R - 1)/(R^n - 1),$$

and R is assumed at 1·05; i.e. the rate of interest upon the accumulating sinking fund is 5 per cent. V is the present value as obtained from Equation (1) above. Of the various systems mentioned by the authors, the sinking fund is the only one that appeals to me at all, although I see no objection to the repayment of a loan by a reducing balance method which consists in setting aside each year a certain fixed sum made up of two parts. One of these is applied to the reduction of the loan and the other is simple interest upon the balance not repaid. The authors' remarks upon equated periods are very much to the point, and I congratulate them also upon pointing out the difference between life limited by work rather than by time. This is often appropriate to machine tools and similar equipment. I agree with the general conclusions of the authors, except that I believe few firms will be bothered to deal with two funds. It is simpler to maintain out of revenue as necessity arises, and to depreciate according to the estimated economic life, which should be

Cramp.

frequently re-assessed, and which should reckon upon a final value as scrap only. While the control of the Local Government Board has been salutary in forcing local authorities to provide sinking funds, it also has its disadvantages. I believe it to be a fact that in many parts of the country there is obsolete plant which is never used, but is kept in position waiting for the repayment of the loan wherewith it was purchased. In many cases it would have been advantageous to scrap such plant and invest the resulting money rather than to keep it in position.

Foden.

Mr. W. E. FODEN (*communicated*): I am in general agreement with the authors' views, but I deprecate the idea that accountants presume to treat the subject as theirs alone. Regarding the choice between the various methods of providing for depreciation, I think the sinking fund method perfectly sound and the only one worth consideration, and I should like to call attention to the general use by English municipalities of that method in connection with debt redemption. As Accountant to the Manchester electricity undertaking I cannot, however, see why concerns such as electric supply undertakings in municipal control should keep two separate sets of calculations—one based on physical lives and the other on economic lives. The last-named are all that seem necessary. Moreover, the annual recording of data and calculations involves considerable expense, so that the extra cost would have to be well justified if incurred. The possibility of sale as going concerns by municipalities may, of course, be dismissed. For these undertakings the value of calculations based on economic lives lies in the test they afford as to whether the debt redemption charges determined by the Local Government Board equal or differ from such depreciation. If they equal or improve on it the position is clear for raising fresh capital by loans as permitted by the Local Government Board, the old capital in the circumstances premised having been repaid within the economic lives.

Mr. Foden.

(The AUTHORS' reply to the discussion will be found on page 226.)

BIRMINGHAM LOCAL SECTION, 17 JANUARY, 1917.

Sayers.

Mr. H. M. SAYERS: The authors have put forward the correct view of depreciation in a way which should convince engineers generally. Their surprise at the indifference expressed by some engineers is justified. Personally I have found it necessary to consider and calculate depreciation charges very fully and carefully in considering alternative plans, improvements, the prospects of proposed undertakings, and the selling values of existing undertakings. In the case of sales on "tramway terms," it is the value of the physical structure which has to be determined, and that can only be done by ascertaining the deduction from the new value due to accrued depreciation and the remaining value of the plant, which again involve future life and depreciation. In the case of sale on "going concern" terms, what is really bought and sold is the maintainable revenue, and that involves future provision for renewals, based on the existing condition. It would make for clearer views if the provision were named definitely "renewals," instead of "depreciation." An engineer is sometimes placed in a difficulty in making a choice of plant by ignorance of the true cost of raising the capital for a scheme, information which some financiers are reluctant to give. This affects the real rate of return required on the cost of the plant, which may be materially below the capital obligations incurred, and thus vitiate the calculations. It may seem to some a little strange that the authors have put together the return on capital and depreciation provision. This is, however, a correct view. The plant, from the accountant's standpoint, is a debtor to the proprietor or contributor under two heads. The first is that of return on capital, i.e. profits, whether dividends or interest; the second is that of return of capital in such measure as to maintain the value of the undertaking by adequate renewal: a reduction of capital liability. There is some difficulty in calculating the economic life of plant. It requires something of the prophetic instinct, since it involves an estimate or forecast of future developments in the art. It is rather a question whether a provision for improvements is a necessary criterion of the soundness of an undertaking. If the substitution of new for old plant will bring in a sufficient increase of revenue—whether by economy in operation or increased earnings—to provide a proper return on the expenditure, including the wastage of the unexpired physical life of the old plant, it may be quite sound to raise new capital for the purpose. On the other hand, the period at which it is desirable to make such expenditure may be unpropitious for the raising of new capital, and the new investors may demand not only the increase of revenue from that expenditure, but some share of the existing revenue, as leaving the original proprietors worse off instead of better. Therefore it is very nice to have an improvements fund available and greatly to the interests of the proprietors, though hardly essential to financial soundness. The sinking fund method of accumulating renewals and improvement funds, as advocated by the authors, is undoubtedly the sound and equitable one, and is the one which I have always adopted in calculations. Their proof of its equity as between successive owners (or successive periods) is ingenious and convincing. It does not fulfil the demands of some accountants that the value of the plant and of the renewals fund taken together should at every moment equal the original capital. This ultra-view seems to be based upon the fallacy of taking the existing present value of the renewals fund but omitting to recognize that against that they must take the present value of the future liability of renewal, this item they take at its full value as an immediate liability. With reference to the distinction between maintenance and renewals, there seems to be no dividing line in principle. It is, however, convenient as equalizing charges in successive periods, to draw the line at the life corresponding to the accounting period adopted—whether one year or any other period. Then renewals of any portions of the plant having a life period not exceeding the accounting period are charged as maintenance, while those of longer life are provided for from the renewals fund. This avoids anomalous differences between the periodic accounts, which, as the authors point out, are objectionable and—possibly—inequitable. The absence of the word "obsolescence" from the paper is an additional reason for thanking the authors.

Mr. Sayers.

Mr. [illegible]: The paper has apparently been written to show the superiority and greater accuracy of the sinking fund over the straight line method of computing the depreciation allowance for plant, and the authors have made out an exceedingly strong case for the employment of sinking fund calculations in the preparation of ordinary commercial accounts. Mr. Gill has, however, mentioned in his introductory remarks that the paper is not intended to relate to the accounts prepared by municipalities working on borrowed money, and possibly the same applies to a concern run by the State, as the telegraph and telephone systems. Anyhow, for the purpose of "considering the financial results of the working by the State of the telephone system of the country" the Postmaster-General appointed in 1913 a strong committee of accounting, actuarial, and engineering experts, and, in preparing the statement of accounts for presentation to Parliament, they assessed "depreciation on the basis of the estimated effective life of the plant." The method followed was on the straight line basis of equal annual instalments on an equated life of plant of 20 years (as estimated by the Engineer-in-Chief of the Post Office), due regard being paid to residual values.* No doubt this decision was arrived at, as against the sinking fund method, to conform with the usual practice of annual accounting for Government departments, each year's votes being entirely independent, and to fit in with the system of Parliamentary control. The authors may like to know that for some years past we have in the Engineering Department of the Post Office prepared estimates for alternative schemes of carrying out works, on the basis of a comparison between the present values of the total annual charges, covering capital cost, depreciation, maintenance, etc., as advocated in the paper. There can be no doubt about this as the true method for arriving at the accurate costs of works, instead of paying so much attention to mere capital outlay. Referring to the "constant maintenance cost" section of the paper, it is not my experience that the maintenance cost of telegraph and telephone plant is constant throughout its life. In the case of line plant, the maintenance cost is at a minimum for the first few years, then as time goes on arms require straightening and wedging, wires get slack and have to be regulated, insulators, binders, stays get loose and have to be tightened up, all this having no connection with mere renewals in the sense of plant replacement. Again, a switchboard multiple gives comparatively little trouble when new, but when it approaches the end of its effective life, the jacks get worn and further troubles arise in the removal of faults in a large multiple field, which considerably add to the maintenance cost. The illustration given of faulty cable renewal only holds good where a considerable length of cable is replaced. For ordinary faults only a very short piece of cable is replaced, and the cost of [illegible] small length is high compared with the jointing and other costs of a renewal length. Possibly, however, this extra charge might be regarded as proper to maintenance instead of renewals, and shows how the two are so closely [illegible].

Councillor [illegible] Marks: The authors have demonstrated the advantages of the sinking fund method of providing for depreciation of plant. The particular method adopted is not, however, of such prime importance as the need for making the provision adequate. Engineers, like other people, are in danger of overlooking the needs of to-morrow by their anxieties of to-day. If they can keep the concern running now they are apt to pay too little attention to the avoidance of difficulties for their successors. It is impossible of course to have a healthy continuing business on such lines. Engineers are well acquainted with the principle of the indestructibility of energy and of matter. They will never command the confidence of those who can finance their undertakings unless they recognize the theory of the indestructibility of capital and make due provision for wasting assets. It is not always easy to estimate the physical life of a plant. It is always difficult to estimate its economic life, and it is the engineer's duty to do it, but not to settle how the money set aside to maintain capital intact is to be dealt with.

Councillor Marks

Mr. F. J. Moffett: In the section headed "constant maintenance cost" it is stated that "the renewal of each part, as it is required in turn, is provided for by the fund established on the basis of the equated physical life. It is therefore clear that an equated life, arranged for all the plant, provides money for the renewal of every part." I should be glad to know whether the authors propose that a physical life should be fixed for every component part of an individual machine and that, from these separate physical lives, an equated life for the whole machine should be arrived at in order to calculate the renewals fund. In the case of a continuous-current generator this would mean fixing physical lives for each item such as armature core, pole-pieces, yoke, armature winding, field winding, commutator, shaft, bearings, and brushes. If this system be adopted in the case of every machine, the process of calculating the equated life for each machine would be somewhat elaborate and the allocation of the proportion of the renewal fund due for the renewal of each part as it failed would be a very complicated matter for the management of the firm or their accountants. It appears to me that a much simpler and more satisfactory arrangement would be that the renewal of all parts such as brushes, bearings, etc., which wear out in a relatively short period, should be charged to maintenance. It would be a comparatively easy matter to estimate the annual cost of such renewals and add this amount to the ordinary maintenance cost.

Mr. Moffett

Dr. C. C. Garrard: This paper brings home the necessity in modern times of accurate cost-keeping. It is rather surprising to find, even among business men, a very vague idea as to what an engineering or manufacturing cost is. It is very often confounded with an estimate, and is regarded as a variable quantity which can be altered at will, depending upon the formula or method of calculation used. This view is however entirely wrong. The cost which has been incurred in making a certain article or in carrying out a certain operation is a fixed and unalterable amount. The cost which will be incurred in repeating the work may well be different; once a job, however, is completed its cost for that occasion is fixed. It may be difficult to find out what the actual cost was, and we may be only able to arrive at approximations of the value; but this value, although unknown, is essentially

Dr. Garrar

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* [illegible]

Dr. Garrard. a fixed quantity. All proper systems of keeping costs aim at arriving at as nearly as possible the correct figure. This question of cost-keeping is as important in a manufacturing works as it is in an electric supply station or telephone system. A works which has not a proper cost-keeping system as a basis for its official accounts, is in the same position as that of a retail shopkeeper who does not know what he has given for his stock. In a manufacturing works, however, the running costs are the most important, as the capital costs are much smaller in comparison. This is by reason of the fact that the annual turnover is generally several times the amount invested in plant. For a manufacturing works, therefore, I do not think the rather elaborate method of arriving at the annual capital costs given in the paper is applicable. Manufacturing being essentially speculative it is necessary, if one is to be safe, to err on the cautious side and to allow very much more for depreciation of plant than is theoretically necessary having regard to the economic life of the plant. The case is very different with such things as electric power systems and the like. With such one may have, say, £2,000,000 invested in plant with an annual sale of electricity of only, say, £350,000. An accurate determination, therefore, of the annual capital charges is absolutely necessary to settle whether the concern is working at a profit or a loss.

(The AUTHORS' reply to the discussion will be found on page 226.)

FURTHER CONTRIBUTIONS TO THE DISCUSSION.

Mr. Dykes. Mr. A. H. DYKES (*communicated*) : It is due, I fear, to the want of clear thinking which has in the past characterized so many of our business methods that even now there should be a want of agreement in the methods to be employed in arriving at a correct figure for depreciation, or even on the exact scope of the term "depreciation" itself. It is a common practice to enter into a maintenance contract with the makers of storage batteries who for an annual payment will undertake during the period of the agreement to provide all renewals as required and keep the battery always up to its full specified capacity. The period of the agreement is generally 10 years, with the option of extending for a further period of 10 years. It may easily happen that during the first five or even eight years the makers do not spend a penny on the cells, but during the last two years may renew practically the whole of them, so that at the end of the 10 years the battery is in as good condition as when new, and the agreement is entered into for a further term of 10 years. In several cases the auditors have placed the whole of the annual payments to repairs and maintenance account, and have then stated that nothing has been put to depreciation account, thus giving a false impression of the financial position of the undertaking, and making it compare unfavourably with similar undertakings which have no maintenance contract and have spent nothing for the first five years on their batteries but will inevitably have to renew the greater part of the plates within a very short time. I contend that a payment under such a maintenance agreement should be allocated partly to repairs and maintenance and partly to depreciation account, and that a company which enters into such an agreement is making a contribution to depreciation account quite as much as another company which has no maintenance agreement but puts by a definite sum per annum based on the expected life of the battery. I have, however, had difficulty in getting auditors to see this. My opinion is that a depreciation fund should provide money for the replacing of the plant at the end of its working life, all renewals of parts during that life coming under the heading of repairs and maintenance, and that the depreciation fund should make no provision for the replacement of old but still usable plant by improved, more economical units. Any money required for this latter purpose should come out of a reserve or improvements fund, or from new capital or loans raised for that specific purpose, the charges on which should be met out of the savings effected by the new plant after providing for any outstanding capital charges on the old plant put out of commission. Many business men, however, seem to consider the depreciation fund as an "omnibus" fund to cover all contingencies. When it is pointed out that the sums which they consider should be allocated to depreciation will by the time the plant is worn out amount to a sum considerably in excess of the original value of the plant, they reply that they like to have something in hand and that they may want to replace it before it is worn out.

A clear understanding of the principle of depreciation is important, not merely when estimating the value of an electricity supply undertaking, but also, as pointed out by the authors, when considering the adoption of new and improved plant. This paper is therefore especially opportune at the present time when the whole nation is taking stock of its old methods and bracing itself for the strenuous competition which will follow the close of the War. Electrical engineers can justly claim to have been largely instrumental in inaugurating improved and more scientific methods of measurement in engineering works, and it may be that the authors' paper and the discussion which it will arouse may be instrumental in leading to more accurate methods of dealing with the depreciation fund. The real difficulty is that in many cases the commercial men and auditors do not clearly distinguish between the depreciation fund and the reserve and improvements funds. In the past many works and manufacturing businesses have left the question of the depreciation on their engineering plant entirely to their auditors, who, without in many cases considering very carefully the probable life of the plant or the scientific principles involved, have simply written off 10 per cent per annum, the interest on the money in the depreciation fund going into the general business (I fear that not many purely electrical undertakings have been able to set aside so large a sum). At 4 per cent interest an annual payment of £10 would form a sum of £100 in something under nine years; it is therefore evident that on the above plan long before a boiler, an engine, or a system of underground mains is worn out its capital value has been written off and it stands in the books at nothing. "A very good thing too," I fancy I hear someone say : but there is [illegible] to it. The old plant may be antiquated, wasteful, and uneconomical; but if it were proposed to replace it by new plant after taking out the running cost and the cost of maintenance of the new plant, 10 per cent per annum would be added for depreciation, with the result that as the charges on the old plant had been already written off, the real advantage of the newer, more economical plant would be obscured and a very fine excuse provided for doing nothing and letting the old plant run on.

Take as a concrete case a works having an engine costing originally £5,000. After paying all running cost, repairs, maintenance, and insurance, they would probably write off £500 per annum for the first 10 years. If at the end of 20 years a proposal were made to put in a new and more economical engine costing also, say, £5,000, the estimated or guaranteed running costs and cost of upkeep of which showed an annual saving of £800, they would deduct £500 per annum for depreciation on the new plant, thus showing from their point of view a saving of £300 per annum only. The correct method, as the authors so convincingly show, would have been as follows:—First to have made an estimate of the probable life of the engine, say 25 years. At 4 per cent compound interest the annual sum required to produce in 25 years £4,500, the original less the scrap value of the engine, is £108. If this sum had been put to a depreciation fund, at the end of 20 years they would have paid into it £2,160, which at 4 per cent compound interest would by that time have amounted to £3,216, the plant thus standing in the books at £1,784. Assuming the estimated life of the proposed new engine to be 25 years, the amount required for depreciation would also be £108, and as the saving in running costs was estimated at £800 per annum, the net saving by putting in the new plant would be £800 per annum, less, for 5 years, £108, the amount still to be paid off on the old plant. This puts a very different complexion on the proposal, and shows clearly the necessity for adopting correct procedure as regards depreciation. To put it another way, if the firm in the first instance had said: "Although £108 is theoretically the proper sum to put to depreciation each year, we prefer to have something in hand for contingencies or possible improvements and will therefore set aside 10 per cent, i.e. £500 per annum for 10 years," then after placing £108 per annum to the depreciation fund, £392 per annum should have gone to a reserve or improvements fund. At the end of 10 years this latter fund at 4 per cent compound interest would have amounted to £4,705, the interest on which, viz. £188, would have been more than sufficient to pay the depreciation fund charge of £108 for the remaining 15 years, whilst the capital sum together with the balance of the interest after providing the £108 would at the end of 20 years have been more than sufficient to pay the whole cost of the new, more economical, engine without having to take from the general business fresh capital for that purpose. It is true that at the end of the life of the plant the net result to the firm's business as a whole would be the same whichever method were adopted, but the above example makes it clear, I think, that the straight [illegible], in failing to distinguish between [illegible] and by not crediting the depreciation account with interest on the sums paid into it, confuses the issues and renders it difficult to appreciate exactly the benefit, or the reverse, of any proposed change. Mr. Dykes.

Mr. W. Schooling (communicated). Perhaps my best chance of making a useful contribution to the proceedings is to show how the identical problems with which engineers are concerned have been solved in connection with another business with which engineers, as such, have little to do. If it is once granted that depreciation is a financial problem, it may be said with confidence that there is no aspect of it which has not been dealt with successfully in connection with life assurance, and that on lines which are universally accepted as correct and as admitting of no alternative procedure. In regard to plant the engineer corresponds to the medical examiner for life assurance. He has to estimate the duration of life. It is true the medical examiner has at his disposal tables of mortality which embody past experience and give the probable duration of healthy life according to age; but the doctor has to estimate as nearly as he can the probable deviation from the healthy standard due to family history, physical condition, symptoms, and habits of the life to be assured. The engineer on the other hand must in effect construct his mortality table of the plant largely on the basis of his own experience, although I can imagine that a small committee of engineers could arrive at approximate agreement as to the probable life, physical or economic, of a large number of different types of plant. Even without the extensive data in regard to the duration of life of plant, such as exist in connection with human lives, the engineering estimate of duration of life is to a great extent free from the extreme fluctuations which are exhibited by human mortality. A man may be assured to-day and die to-morrow, or he may live to be a centenarian; but when human lives are dealt with on an extensive scale these extreme fluctuations in length of life are completely covered by the methods adopted for valuing lives or, as we may put it, calculating their depreciation. The physical life of plant erected to-day is not terminated to-morrow by depreciation. It may be destroyed by fire or accident, but that is presumably covered by insurance. Even the economic life of plant can be judged with far greater accuracy by an engineer than the duration of an individual life can be determined by a doctor. For more than a century it has been recognized that the annuity or sinking fund method, for they are essentially one method, is the only plan that can be adopted. It is theoretically perfect and complete, and has received the most practical possible proof of efficiency in the success of life offices which are the safest financial institutions of the world. Let us consider the different identities—for they are much more than analogies—in connection with engineering plant and human life. The sum assured under a life policy corresponds with either the cost of new plant when the existing plant dies or with the return at the death of the plant of the capital originally invested in it. The annual cost of depreciation corresponds to the annual premium for life assurance. The net or theoretical premium for life assurance consists of two portions, one of which is set aside and accumulated at compound interest as in a savings bank, and the other is used to pay for insurance protection, for an amount which is the difference between the sum assured by the policy and the accumulated savings standing to the credit of the policy-holder as in a savings bank. A Mr. Schooling

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man pays a first annual premium of £30 for a policy of £1,000. If he dies in the first year nearly £1,000 in excess of the amount standing to his credit is paid to his heirs, and this is a risk strictly akin to fire insurance, towards the payment of which the whole body of the policy-holders contribute. The risk and consequently the cost of the protection is great at old ages and small at young ages. The system provides complete facility for dealing with either large or small chances of the sudden termination of life. In connection with engineering plant the chance of a sudden termination of life, excluding fire or accident, is extremely small, whether we are dealing with the physical or the economic life; but the principle is in close correspondence with that of life assurance, which provides a sinking fund, or accumulating savings bank deposits, for the purpose of meeting a claim at the termination of the life.

Another class of contract into which life assurance companies enter consists of pure endowments, or leasehold policies, or as they are sometimes called sinking fund policies. Here the term is definitely fixed: in return for, say, 20 annual premiums the life office undertakes to pay a specified sum at the end of 20 years, and at no other date. Engineering plant has a nature that is intermediate between leasehold policies on the one hand and life policies on the other. The duration of the life of a plant cannot be exactly determined like that of a lease or a debenture issue; but on the other hand it can be much more closely estimated than the life of a human being. Life offices, however, adopt identical methods for dealing with the precisely known duration of a lease and the vaguely known duration of an individual life. So far as I am aware there has at no time existed even a crank who disputed the fitness and the necessity of the life-assurance method of making financial provision for payment at the end of the fixed life of a lease or at the end of the uncertain life of an individual. Engineering plant is in between these two, the life being less definite than the one and more definite than the other, and I cannot but think that, if engineers had made themselves acquainted with the methods of life offices in this connection, there would have been no room for a discussion as to the methods to be adopted for calculating depreciation when once the necessary data were supplied by the engineers. We may talk of the average duration of the life of plant being 19 years, the period used by the authors; but it is improbable that all items of plant of the same kind will come to an end like the "one-hoss shay" at an exact date. We may assume that some may die sooner, and some survive longer than the estimated length of life. In the absence of any special knowledge on the subject we may fairly work on probability figures, and if we reckon that the depreciation is spread over a period of seven years we should expect some such results as the following:—

Age		Deaths
16 years	... ...	1
17 ,,	.. ...	6
18 ,,	... ...	15
19 ,,	... ...	20
20 ,,	... ...	15
21 ,,	... ...	6
22 ,,	... ...	1
		64

Mr. Schooling.

We can extend or shorten the period during which the lives of the different items of plant come to an end, and thus arrive at a curve corresponding with that of Fig. 7 in the paper. It might well be that some preliminary period could be reckoned upon during which there would be no cessation of life, and a subsequent period beyond which no plant would survive. The annual cost of the depreciation in such a case would take account of this varying plant mortality and could not accurately be calculated on the mere average life of plant of a particular type.

If the life-office example were followed, the various items of plant would be valued in groups, and for each item in each group a premium, or annual payment for depreciation, should be made. When an item came to an end its replacement value, less its scrap value, would be a claim on the depreciation fund, and no more annual payments would be made on account of that item of plant. When a new item of plant was introduced into a group it would commence to pay a premium just like a new policy-holder in a life office. If it were thought a prudent measure, it could be arranged that the cost of plant should be paid for by the end of a fixed period, or at the cessation of its life if previous, thus providing an exact analogy with endowment assurance. The total amount of the depreciation fund would be easily ascertained, since it would increase by the depreciation payments for the various items, together with interest, and would decrease by the claims for replacement after deducting the scrap value. It seems to me that there can be no doubt that this is the rational and accurate way of dealing with the subject, but it is not practically possible to adopt this method, any more than it is practically possible to conduct the business of life assurance without the use of tables. The valuation tables required for engineering plant would be of an exceedingly simple character, and with their help the proper annual charge for depreciation would be simply and easily determined, and the amount in the depreciation fund could be quite quickly ascertained. The diagnosis that the engineer would have to make would practically amount to that of the average lifetime, accompanied by an estimate of the period, less and greater than the average, during which the lives would come to an end. In actual fact a problem far more difficult and complicated than anything with which engineers have to deal has been completely solved in connection with life assurance. There the conditions of the problem are extremely complex: in engineering, by contrast, they are the quintessence of simplicity, and I venture to submit that engineers will not have applied to this important question of depreciation the scientific methods and the system of standardization from which in other directions they derive such great advantages, until they have applied, in a vastly simplified way, the methods which have been established in life assurance, and which have been proved by long experience to be incontestably sound. In conclusion, I would say that I am in complete agreement with the paper, except that I would extend the "sinking fund" method to what may be called the "life assurance" method, by providing for a fluctuation period each side of the average during which the lives of plant come to an end.

(The AUTHORS' reply to the discussion will be found on page 226.)

Messrs. [illegible] and W. W. Cook (*in reply to the discussion before the Yorkshire, Manchester and Birmingham Local Sections*): Many of the questions raised in the discussions before the Local Sections have already been dealt with in our reply to the London discussion,* and in replying to the further points we have, as far as possible, adopted a similar method of treatment. We have not referred specially to many of the speakers who supported our views, but we have tried to reply to all important criticisms of the principles advocated, with the exception of some consisting of mere assertions unsupported by reasoned arguments.

Questions have been raised regarding the necessity for equated lives, and whether it is not sufficient to ascertain the amounts payable to each fund for each sub-class. Of course, if the amounts for all the sub-classes are ascertained the total is the sum required, but it is often very inconvenient to refer to the matter in this detailed way. In a complex plant there may easily be 30 or more sub-[illegible]ch with its physical and economic lives, and it [illegible]ly easier in such a case to refer to the funds as [illegible] based upon the equated lives of, say, 19 and 25 [illegible], than to give each of the separate lives, or contributions, resulting from the individual items. In view of the space devoted in the paper to the difference between average and equated lives it is somewhat surprising that we should be asked for a fuller explanation, and still more surprising that because we insist on this difference we should have been accused by Mr. Beckett of having got confused. The equated life in Table 10 is not 5·66 years, but is, as stated, 3·75 years; it cannot be disputed that £74·83 per annum is required and if the life were calculated at 5·66 years only £47·10 would be provided, whereas a fund calculated on the basis of 3·75 years will make adequate provision, as shown in Table 11.

[illegible] storage battery where there is a contract to maintain and renew it; provided that the [illegible] cannot relinquish his contract except when the battery is in 100 per cent condition, apparently such a battery is provided against renewals during physical life, and the value of the battery plus the transferable contract is always 100 per cent. If the contractor can give up the contract when the battery is not in 100 per cent condition, provision to meet that degree of depreciation is required in the renewals fund. The extent to which renewals is covered depends on the contract; [illegible] some provision for renewals is included in the total payment to the battery contractor, and this portion is not a maintenance charge; it seems clear also the improvements fund is not provided for by such a contract.

It is said that owing to renewals being sometimes carried out in portions, the cost of renewing will be greater than that of original construction, and so there will not be enough in the fund for the purpose. But the [illegible] real data in [illegible] the [illegible] up of [illegible] the first cost, (*b*) the additional amount dependent upon piecemeal renewal (if of sufficient magnitude [illegible] residual [illegible] plant [illegible] more to remove at the end of life than the materials are worth, resulting in a negative residual value, as illustrated in Table 12, sub-class C.

Messrs. Gi
and Cook.

The question whether the contributions to the "improvements fund" are properly part of annual charges has been raised by several speakers, and, as it is a very important point, it is necessary to deal with it at some length.

Taking the case of plant having the agreed lives and residual values used in Tables 1 to 9, and supposing that it is owned by one person and operated by another, what would be a proper rental to charge for the use of it? If the improvements fund is no part of annual charge it is clear that any contribution to such a fund should not be included in the rental, and the annual capital charges will be as given in Table 8, £7·05 per annum.

At the end of 19 years (the economic life) the lessee, if the conditions of the contract permit, will terminate the contract and the lessor will have on his hands plant, standing in his books at £100 − (£2·0533 × 30·589) = £37·20, which can only be sold for its residual value £13. If the rental had been fixed on the economic life of 19 years, it would have been £7·85 per annum and at the end of the term the plant would have stood at £13, its residual value. It follows that the owner must either insist on having an agreement extending over the physical life of the plant, that is 25 years at £7·05 per annum, or must offer an alternative for a term of 19 years at £7·85 per annum. The lessee has now the choice of three alternatives: (1) to pay £7·85 per annum and at the end of the 19 years be in a position to rent new plant which will turn out work on competitive terms; (2) to pay £7·05 to the owner and make a provision of £0·8 on his own account which will make him equally safe; or (3) to pay £7·05 per annum for 19 years and continue to pay this rental from the end of the 19th year to the end of the 25th year out of savings effected by new plant, although the old plant is no longer in use. In all these cases the rental must come out of revenue, and in the last case the lessee is not on equal terms with possible competitors and is not in a financially sound position, as his assets are not equal to his liabilities.

One of the arguments put forward in favour of providing for the wastage by raising new capital is that the method advocated in the paper puts an unfair burden on present shareholders and that future shareholders will reap the benefit of the savings effected. One answer is that the price of the product may have to be reduced either by competition or by inability to justify the charge by demonstration of costs; but apart from this, it can be shown that the wastage cannot be distributed among those who are alleged to get the benefit unless the critics abandon the theory that the provision for wastage is no part of annual costs. If the wastage is to be written off during the physical life of the older plant the particular shareholders from the 20th to the 25th years will be too heavily mulcted; if it is written off over the physical life of the new plant, the deficit will become larger and larger each cycle, and if it is written off over the economic life the principles laid down in the paper are followed, while in all three cases the charge is included among annual costs. To be consistent Mr. Beckett must exclude insurance premiums from annual charges if, as he states, "it is certainly not true accounting to charge against the

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* [illegible]

ssrs. Gill
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plant for any period more than has been taken out of the plant within that period in earning the revenue."

Some misunderstanding has arisen over the difference between the residual values at the end of economic and physical life. Some have contended that no such difference exists, and others that the difference is too great. In Table 12 it will be noticed that we gave examples of three sub-classes of plant A, B, and C. In A the difference in residual values is great, but in B and C there is no difference at all, and as we were dealing with principles only, we thought that this treatment would show that every case should be examined and the facts ascertained. In a complex structure it will often be found that when the structure is taken out of service many of the component parts can be used again, and of course this must be taken into account.

As we stated in the paper all the tables are illustrative only, and we expressly disavowed any intention of setting up standard rates, but we are afraid that more than one critic has not fully appreciated the fact that throughout the paper we dealt with principles only.

Dr. Cramp has given some general formulæ which may be of assistance to those interested in the mathematical treatment of the subject and Equation (2) for obtaining the reducing balance percentage is in a very convenient form. With reference to Col. D in Table 6, we think the correct formula is $(100-S)(R-1)/(R^n-1)$, but in practice all the figures with the exception of those dealing with the reducing balance method can be obtained from well-known books of tables such as Inwood's.

Dr. Cramp's opinion, that in attacking the straight line method we have erected an anachronism for the sake of knocking it down, will hardly be shared by those interested in electric light undertakings working under Provisional Orders who are aware of the fact that it is the method which has always been followed in sales governed by "tramway terms."

We fail to see any justification for his remark that we have treated annual charges as though they consisted of operating costs alone, and a reference to "annual charges" on page 138 is sufficient to disprove this statement.

Mr. Dykes gives a very useful illustration of how a wrong method may tend to retain really uneconomic plant in service. The wrongness, as he points out, lies in assuming that because plant stands in the books at a certain figure (arrived at by means of merely convenient writings-off), that figure is in fact its value, whereas of course the two are entirely separate and the value must be ascertained independently. This real value is required in a scrapping calculation regardless of how the plant has been written down in the books.

Mr. Lackie in his example does not give figures to enable us to follow him completely; we fancy, however, that it contains a similar assumption, viz. that because the plant has been written down to £7,000, that figure is the value of the plant to be scrapped. With regard to this being a paying proposal, we should like to see the figures set out as in Mr. Byng's illustration on page 159. We assume Mr. Lackie has calculated the saving of £20,000 per annum in coal for only that part of the 6,000 kw. which represents the replacement, i.e. 1,500 kw., since there is probably little saving to be claimed in respect of the additional 4,500 kw. which is new plant and does not replace anything.

Messrs. Gill and Cook.

Mr. Plummer mentions that the Post Office now makes use of economic selection as advocated in the paper; this was to be expected, bearing in mind the recent influx of men into the Department who had been accustomed to those methods. He does not say whether in these calculations the Post Office uses the straight line as in their commercial accounts, or the sinking fund method. But since the paper was read there has appeared a Report of a Committee (which included some of the highest officers of the Department) on High-speed Telegraphy, and in Appendix C, Schedules 2 and 3, there are forms for ascertaining the total costs for the purpose of comparing rival systems of high-speed telegraphs. The method there set up of computing depreciation is the sinking fund method. We thus have the contrast that when the Department desires to get accurate costs it adopts the sinking fund method, while when it wants to present its accounts it adopts the straight line method because, as Sir Charles King says, "(*a*) it is the safer course, and (*b*) it is simple"; a very good example of the engineer and the accountant working on different lines.

We rather think Mr. Plummer has not gone far enough in regard to the increasing cost of maintenance, and we do not believe he can show the effect in reality. We are quite prepared to admit cyclic maintenance costs, as for example in the case of painting referred to in the paper, or in the case he mentions of tightening stays, but we do not believe it can be shown that apart from renewals there are good grounds for asserting that the maintenance cost is a function of the age, or that there is an increasing frequency of maintenance-cost cycles.

A few speakers have considered that too much attention was devoted to an examination of the straight line method and too little to the reducing balance method. The only occasion when the reducing balance plan is favoured, even by its supporters, is in the assessment of profits, and any attempt to use this method on any of the other occasions referred to in our reply to the discussion in London is quite out of the question.

Mr. Platts says that he has frequently advised an initial depreciation of 25 to $33\frac{1}{3}$ per cent immediately on the installation of plant, but we do not think that anyone would care to sell on this basis the next day.

Mr. Walton justifies the method on the plea of maintenance increasing with age, but apart from the fact that we think that maintenance is often confused with renewals, we may refer to the last sentence under constant maintenance cost on page 153 of the paper.

A question has been raised as to the extent to which separate lives have to be assigned to component parts of a machine. It will generally be found that many of the component parts can be grouped together according to their lives so that the number of separate lives is not so great as might be expected, but when applying any consistent system it is essential to study the matter in detail to avoid either double provision under the headings of depreciation and maintenance, or of making no provision at all under either heading. In practice it will be found that the knowledge gained from each particular case studied in detail becomes increasingly useful in ascertaining how far it is necessary to go to secure substantial accuracy.

Replying to Mr. Whysall's question, we assume the following data: first cost £10,000, residual value nil, value of money 5 per cent per annum, physical life of plant

30 years, economic life not treated, authorized loan period 30 years, actual loan periods 5 years. It will be seen that [illegible] in respect of the expired life of the plant and provision for the repayment of the short period loans are both involved.

The contribution to the renewals fund during each of the first five years will be £151 per annum, based on 30 years' life, and with interest will amount to £832 at the end of the fifth year; at this stage a new loan of £9,168 would have to be borrowed, which, with the amount of £832 in the renewals fund, would pay off the original loan and leave £9,168 as the capital for the next five years. In this next period of five years the contribution to renewals would be £193 per annum based on 25 years' remaining life, and at the end of this period £8,107 would have to be borrowed, which added to £1,061 (the amount then in the fund) would repay the loan of £9,168 and leave £8,107 as the capital for the next 5 years. This process would be continued for each 5 years and at the beginning of the last period of five years the capital would thus stand at £2,816, the contribution to the renewals fund would be £510 per annum, based on 5 years' remaining life, and at the end of the 30th year the fund would be £2,816, thus extinguishing the last loan, leaving the owner at that date with exhausted plant of no residual value, no assets, and a clean credit on which to borrow again. The effect of this is that every 5th year the position is adjusted to what it would have been had the annuity method, illustrated in Fig. 5, been followed, and, as in that case, the increase in charge for renewals is exactly counterbalanced by the reduction in the money required for return on capital.

Mr. Schooling's contribution regarding life assurance methods is very much to the point. As he shows, the difficulties in engineering are small compared with those of life assurance, and his remarks seem to be a complete answer to those who have assumed difficulties with the business man and complicated book-keeping and calculation.

With regard to the provision for a fluctuation period each side of the average life, this may cause serious errors if the plant is not properly subdivided, but if, as we recommend, subdivision is practised, we then think the error in the case of renewals is a minor one, as shown in Fig. 7, where the equated life is 29 years as against an average life of 28·75 years. This point is of greater [illegible] in the case of economic life, and the extent to which it may be necessary to allow for it will depend on the data available in each case.

The reference to assurance companies' practice strengthens our contention with regard to constant revision of data, as the mortality tables now in use have only reached the present state by patient and sustained investigation, and it is certain that if a definite basis had not been adopted in the early days, the same results could not possibly have been achieved.

Many of the contributors to the discussion have attacked the problem from the standpoint of what it is customary or convenient to provide against depreciation. But it seems to us that this is altogether a secondary phase. Let us first ascertain what is the real cost irrespective of any bias for or against any particular method, before discussing the advisability of making more or less provision and the means of doing so under any particular circumstances. No one would say that the amount to be charged in respect of fuel should depend on the result of the year's working, and if Mr. Pearce is right, as we think he is, in saying that depreciation is as much a working charge as fuel, surely some care should be given to its accurate ascertainment. Dr. Garrard sums up the matter most clearly in words that deserve special notice when he says "The cost which has been incurred in making a certain article or in carrying out a certain operation is a fixed and unalterable amount. . . . It may be difficult to find out what the actual cost was, and we may be only able to arrive at approximations of the value, but this value, although unknown, is essentially a fixed quantity." By the constant revision of all data (an important part of the method advocated in the paper), approximations will approach more and more nearly to the actual costs. Lord Kelvin's words* have an appropriate bearing on this as on so many other subjects. "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind, it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *science*, whatever the matter may be."

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* Lecture on "Electrical Units of Measurement," delivered at the Institution of Civil Engineers ("The Practical Applications of Electricity," [illegible]), [illegible]

DISCUSSION ON

"THE PARALLEL OPERATION OF ELECTRIC POWER STATIONS."*

WESTERN LOCAL SECTION, 5 FEBRUARY, 1917.

Mr. W. A. **Chamen**: This paper has already been well discussed and there is very little left to be said, but perhaps some considerations regarding the question of changing over the periodicity of one system to suit that of another may be useful. It is obvious that such a course is always desirable in the interest of simplicity and of the highest efficiency, and in many cases no doubt it is quite a possible and proper course to adopt, but in the case of a supply undertaking having a considerable number of large consumers, many of which are collieries, the problem is exceedingly difficult, if not impossible, and the cost prohibitive. New plant would have to be installed in the power station before the original plant could be put aside. So far as the plant is concerned it might be possible to change it over piecemeal, and it might even be possible to follow the same course with regard to the main switchboard, which is usually duplicated as regards the busbars, so that the new plant could deliver to one set of busbars while the old plant could deliver separately to the other. But the real difficulty would arise in dealing with feeders, upon which perhaps several large consumers may be grouped together. The periodicity of supply to all these consumers must obviously be changed at one and the same time, which means that the consumers must be dealt with simultaneously. The worst difficulty of all, however, is in connection with the consumers' installations. Motors of the new periodicity would have to be provided in readiness for the change, and in many cases it would be impossible to get these motors delivered below ground and transported to their various destinations at the same time that the old motors were being taken out, except by arranging for periods of shut-down of such duration as no colliery would be likely to be able to bear. It would involve practically the construction of duplicate engine-houses or pump-houses underground so that the new plant could be erected before the periodicity was changed. The time taken to carry out such operations and the cost of them would clearly be prohibitive. It must be remembered that the transport of motors and other heavy machinery along the underground roads must all be arranged and carried out in such a way as not to interfere with the ordinary working of the mine, and this in itself would be the cause of very serious delay. It may be taken, therefore, that the question of changing over the periodicity of an extensive system of supply is, practically speaking, quite impossible. It follows then, that in cases of the linking up of power stations running at different periodicities, we should be often driven to the use of frequency changers; and all questions relating to them therefore become of great interest and importance. I know of one instance of linking up of power stations of different frequencies, where energy is sometimes transmitted in one direction and sometimes in the other, in which it has been thought necessary or desirable to construct the frequency changers with motor ends of the induction type and with generator ends of the synchronous type, coupling one in the one direction and the other in the opposite direction, so that the induction end should always be the motor in one or other of the sets, according to the direction in which the load is being transmitted. I gather from the author's reply to the discussion that this is not really necessary, and that frequency changers with synchronous machines at both ends can be used with safety. The fear expressed in regard to this arrangement is apparently that one station might tend through overload to drop its speed slightly and that the synchronous machines, allowing of no slip, would be liable to destruction by being called upon suddenly to transmit loads altogether beyond their capacity. This, however, seems to me simply to point to the necessity for having the frequency changers of ample capacity to deal with any situation which might be likely to arise in practice, and for the use of reactances, automatic overload circuit breakers, or other protective devices to prevent injury to the machines in case of abnormal conditions arising. Surely, after all, this question cannot be really different from that of linking up two power stations of the same frequency, because the same question of the carrying capacity of the interconnecting cable and of the necessity for protecting it against excessive and abnormal loads must obviously arise there. The fact of having to interpose running machinery no doubt tends to accentuate the point, but it exists just the same in either case. Some people who are large users of power, but not electrical engineers, seem to think that it should be commercially possible for an electric power supply company to have duplicate systems of mains and duplicate generating plants so as to give supplies at either 50 periods or 25 periods or even both, as the consumer might find convenient. If that were so, it might remove one of the difficulties of interconnecting, but unfortunately this is only one of the many quaint suggestions which are sometimes made by consumers who know nothing whatever about the generation and supply of electricity. The author has mentioned that surges occurred in certain interconnecting lines having a small cross-section of copper. I should like to know what was the nature of these surges and why it was that apparently an increase in cross-section of copper in the interconnecting line, which presumably simply meant increasing the conductivity of the line, got over the difficulty. Mr. Chamen.

Mr. C. G. **Morley New**: Dealing with the author's summary, I quite agree with the first part of paragraph 1, that stations could be operated in parallel without difficulty, at any rate when the respective staffs have got used to the new operating conditions, and for that reason I cannot understand the emphasis the author makes regarding speed regulation. I think this can be safely left to engineers who have been running plant of all types and Mr. New.

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* Paper by Mr. J. S. Peck (see pages 61 and 175).

Mr. New

ages in parallel successfully. The power-factor question might be troublesome, and I think that at any rate as far as the station is concerned this should be improved. The interconnector voltage will have to be carefully considered, as it is probable in many instances that the linking-up system of to-day will be the transmission system of the future, and extensions to generating stations only carried out in the most suitable places. With regard to the second part of paragraph 1, I see no reason why reliable automatic devices could not be installed for the purpose of earthing a system in the event of the interconnector opening. We rely entirely upon automatic devices for the purpose of protection of cables, etc., and there is no reason why a simple and reliable earthing device could not be designed. The alternative to a rotating machine, mentioned in paragraph 2, where out-of-balance is not serious, is, I suppose, transforming by the Scott system, although it would be somewhat difficult to balance up single-phase plant on the two-phase side. I am interested in this system of transformation in dealing with single-phase load from a three-phase supply, and I am not at all satisfied as to the effect on, say, phase A during a severe overload, such as a fault on phase B, seeing that the neutral point on the three-phase side is not fixed. I note, however, that in Fig. 3 the neutral point is shown earthed, which is contrary to the Board of Trade regulations if the system is already earthed at the generating station. I should like to know if there is any objection in dealing with single-phase load from a three-phase system by ordinary transformer connections, three-phase mesh-connected to three-phase four-wire, the neutral point forming an earthed outer to the single-phase feeder system. In many cases it is not more difficult to balance three circuits than two. In connection with paragraph 3, having had experience with all types of substation converting machines, I can say that the induction machine is the most stable, as the synchronous plant as often as not shuts down when faults occur outside. It has occurred to me that difficulty might be experienced in getting suitable speeds for some frequency change; for instance, in changing from 50 to 40 only one speed is available.

Mr. Kinsey

Mr. A. T. Kinsey: Telegraph circuits still use the earth as a return conductor, and as the current employed on them is measured in milliamperes, it can readily be seen which circuit is likely to suffer if powerful currents can flow through the earth. Since the introduction of electric tramways, telegraph engineers have constant differences of potential between any two earths irrespective of distance, and in general not much notice is taken of them at the present time so long as they do not exceed 2 volts, as their presence can be eliminated. These potential differences are sometimes positive and sometimes negative. In telephony, owing to the extreme sensitiveness of the apparatus, the use of the earth as a return conductor has long been discarded and all public circuits are now metallic. Moreover, the tendency is to terminate such metallic circuits on transformers so that the transmission circuit proper will be quite independent of the earth. There are, however, large quantities of apparatus used in signalling and in supervision which are auxiliary to the transmission circuit, and they rely upon the use of the earth. It can therefore be seen that telephone engineers as well as telegraph engineers will view with great concern any transference of load from one power station to another if it means that large alternating currents of high frequency will pass through the earth.

Mr. Kin

Professor D. Robertson: The figures which the author gives as to the size of frequency changer necessary for connecting two systems makes one wonder whether it would not be better to change over the smaller system in every case in which it is at all possible to do so. Since the changer set involves both a motor and a generator, if it has to be rated as high as 20 per cent of the capacity of the smaller system, it would cost somewhere about 40 per cent of the electrical equipment of the station, and would thus go quite a long way towards paying the station part of the cost of changing over to the standard frequency. Of course there would be the consumers' motors to change as well, which, as Mr. Chamen points out, would be quite impracticable in some districts. It should not be forgotten that so long as it maintains its own frequency, the smaller system will be handicapped: whenever extension is proposed, by the fact that the frequency changer capacity must be increased as well as the generating plant. In connection with the regulation of the engines, the governors will usually be adjusted from time to time, while running, so as to give the desired load transference from one system to the other independently of the inherent regulation of the machines themselves. The author's calculations on this subject will consequently apply, not to the total exchange of power, but to its deviation from the value to which it has been set.

Professo
Roberts

With the object of illustrating the author's statements and calculations about the operation of machines in parallel, I have prepared some locus vector diagrams which I think will assist many of our members in following his arguments. They are based on the same approximate theory as the author's equations, and are thus subject to exactly the same limitations. Figs. K and L have been drawn to show the effects of phase-swinging when two machines are running in parallel without change of field current. They are constructed thus:—Draw a line O A, say vertically downwards, with the distance O A equal to the motion E.M.F. vector of No. 1 machine. With A as centre, draw a circle the radius of which is equal to the motion E.M.F. vector of the other machine; this circle gives the locus of the extremity of the vector for the current in the first machine. Draw the line A I_1 making an angle with A O equal to the phase displacement between the two E.M.F. vectors—to the left if No. 1 is behind (motoring) and to the right if it is ahead (generating). O I_1 is the current in the machines, taking the No. 1 direction as positive. The scale of current is given by the rule that the same length represents a current I and the electromotive force Z I, where Z is the total impedance of the two machines and the connector. O E_1, the motion E.M.F. vector of No. 1 machine, is ahead of O A by the angle ϕ_M, whose tangent is the ratio of the reactance to the resistance for the whole circuit. E_1 makes an angle α with E_2. The projection of O I_1 on O E_1 gives the working component of the current, and therefore also the mechanical power and torque. The machine operates as a generator if this working component lies along E_1, and as a motor if it is in the opposite direction. The construction is easily proved. The resultant of the two

Professor Robertson.

motion electromotive forces, taking the No. 1 direction as positive, is

$$E_{R_1} = E_1 - E_2 = E_1 + (-E_2).$$

Performing the addition vectorially, we get the corresponding vector O E_{R_1}. The current lags behind this by an angle ϕ_M, and is equal to E_{R_1} divided by the total impedance of the circuit. It will be represented by the same length as E_{R_1} with the choice of scales mentioned above. Now let the E_1 vector be fixed, so that its extremity E_1 is a fixed point. Then the extremity of the E_{R_1} vector lies at the distance E_2 from that of E_1, and therefore moves in a circle with the latter point as centre. By turning the vector parallelogram backward by the angle ϕ_M, E_1 (the centre of the locus circle) is brought to A, while at the same time E_{R_1} is made to coincide with I_1. Fig. K refers to the case in which the resistance of the circuit is negligible in comparison with its reactance, while Fig. L deals with that in which it is appreciable. In both cases, No. 1 machine is supposed to be motoring. A study of either diagram will show that :—

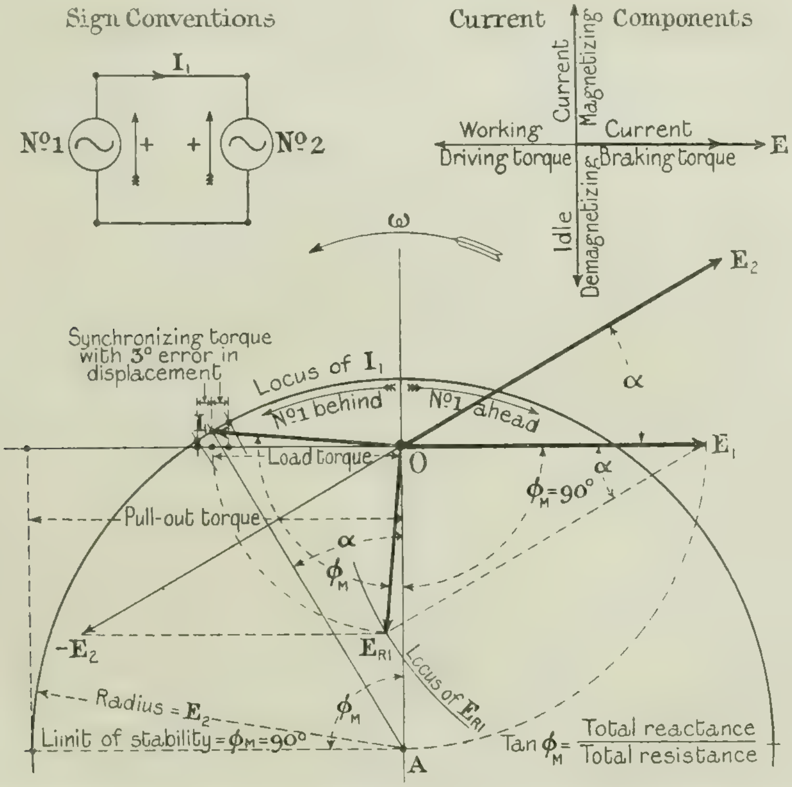

FIG. K.—Locus vector diagram showing effects of phase swing when two alternators are running in parallel with constant excitation. (Resistance of circuit negligible.)

(1) If No. 1 machine gets a little further behind than is required by the load, it gets an excess of driving torque which pulls it forward into step.

(2) If it gets ahead, the driving torque becomes less than the load, and the difference pulls it back into step.

(3) Under the conditions shown, the equilibrium is therefore stable.

(4) The bigger the load, the greater the inclination to the E_1 vector of the locus circle in the neighbourhood of I_1, and therefore the smaller the synchronizing torque with a given phase error, and the less the stability.

(5) The maximum torque occurs at that point where the projecting line touches the locus circle, at which point the stability vanishes and beyond which equilibrium would be unstable.

Comparing one diagram with the other, it may be seen that :—

(*a*) The presence of resistance diminishes the torque with a given phase displacement, and therefore also the maximum torque.

(*b*) It has increased the inclination of the locus arc to E_1, and has thus diminished the stability with a given mean displacement.

(*c*) The phase displacement necessary for a given torque has been increased by the presence of the resistance.

(*d*) Consequently the stability with a given load has been very much reduced.

If the two diagrams refer to cases of equal impedance, but made up in different ways, the current, power, and torque

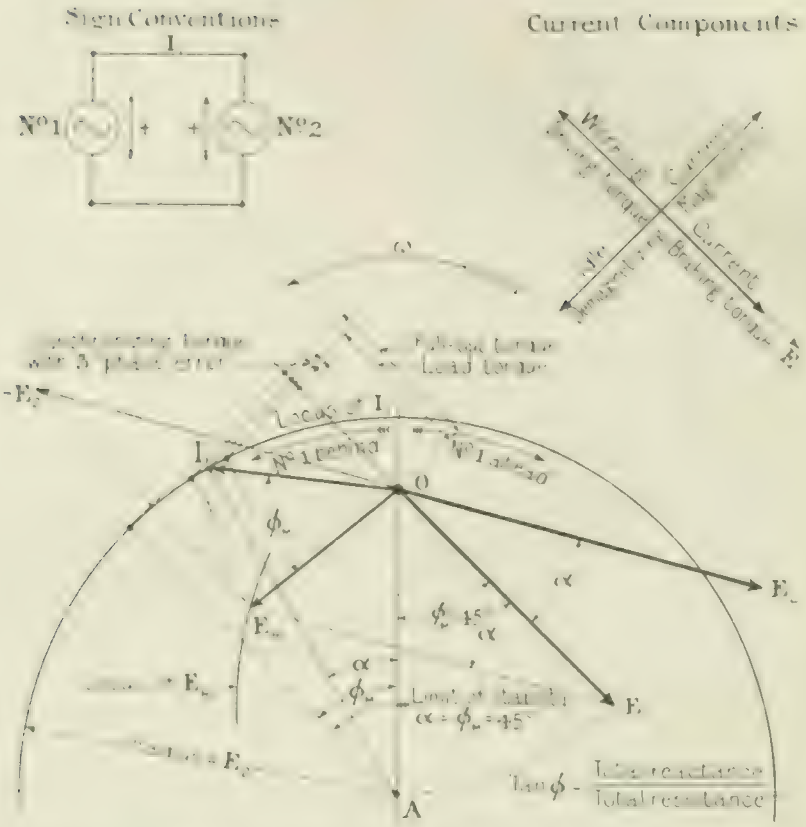

FIG. [illegible]—[illegible] running in parallel with constant [illegible] ([illegible] half of reactance.)

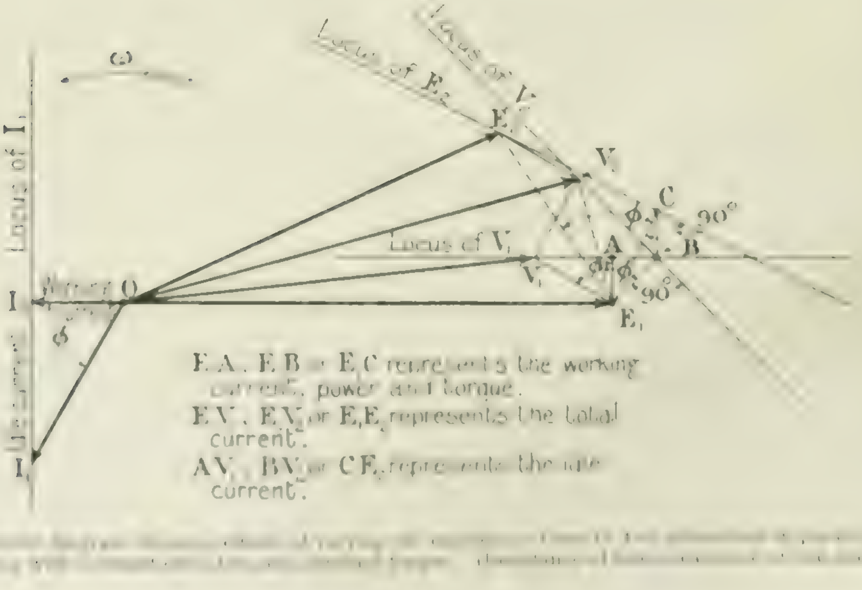
ω
Locus of I₁
Locus of E₂
Locus of V
E₂
V₁
C
φ
90°
Locus of V₁
A
B
V₁
90°
I
O
E₁
φ
I₁
E₁A, E₁B = E₁C represents the working current, power and torque.
E₁V₁, E₁V₁ or E₁E₂ represents the total current.
AV₁, BV₁ or CE₂ represents the idle current.

FIG. [illegible]

ssor rtson.

scales will be the same for both. But if the resistance in Fig. L is an addition, say a connecting cable, to the reactance of Fig. K, the impedance will be greater, these scales greater also, and the conditions for the second case even worse than they appear from the diagrams.

Fig. M is intended to show the voltage variations when No. 1 machine is running with constant excitation and constant torque, while the excitation of No. 2 is varied. Both machines are supposed to have reactance without appreciable resistance, and they are connected by a line having considerable resistance but no reactance. For a constant torque, the working component (with regard to the motion E.M.F., not the terminal potential difference) of the current in No. 1 must be constant; hence the locus of the extremity of the current vector is a straight line perpendicular to OE_1. The minimum current for the given conditions is OI_0, in line with OE_1. With this current, the reactance voltage in No. 1 machine is E_1A, so that its terminal voltage is OA (not drawn in). The resistance voltage of the line is AB, and the terminal voltage of No. 2 is OB (not drawn). The reactance voltage of the latter machine is BC, and so it must have the motion electromotive force OC (not drawn) if the current is to be a minimum. The actual vectors drawn in correspond to any other condition. E_1E_2 represents the total impedance voltage, made up of the three components E_1V_1, V_1V_2, V_2E_2, as before. Since the reactance voltage makes a fixed angle with the current, and E_1A was its direction when the current was OI_0, it follows that the angle AE_1V_1 is the same as I_0OI_1. But E_1A was reactance $\times OI_0$ and E_1V_1 is reactance $\times OI_1$. Hence the two triangles AE_1V_1, I_0OI_1 are similar, and consequently the angle at A is a right angle like that at I_0. Thus the locus of V_1 is a straight line through A at right angles to E_1A; that is it is parallel to OE_1. In a similar manner, by taking the partial impedance voltage E_1V_2, and the total impedance voltage E_1E_2, it can be shown that the locus of V_2 is a line through B at right angles to E_1B, and of E_2 one through C at right angles to E_1C. The effects of altering E_2 can be easily traced out from the diagram if it is remembered that the three lines E_1V_1, E_1V_2, E_1E_2, all make equal angles with their shortest positions E_1A, E_1B, E_1C, and also that the length of any of these lines can be taken to represent the magnitude of the current to the same scale as its minimum length represents the minimum current. The perpendiculars from E_1 to the three locus lines represent also the power and torque, while the distance of the E.M.F. vector-end from its minimum current position gives the idle current.

Nelson.

Mr. T. J. Nelson (*communicated*): This paper, which has come at a very opportune moment, provides a strong argument for the standardization of frequencies, as the difficulties that arise with the parallel working of power stations appear to be in connection with frequency changers. The parallel working of two power stations having different frequencies has been successfully carried out in South Wales at the "New Markham" pits of the Tredegar Iron and Coal Company. These new pits have a supply from two existing stations belonging to the Company situated at Tredegar and Oakdale. These two stations, however, have different frequencies, Tredegar being 40 periods and Oakdale 50 periods, and in order to be able to use either supply it was decided to install frequency changers. These are used at the same time so as to interlink the two stations, enabling them to assist each other. Two motor-generators were installed, one with an induction machine on the 40-period side and the other with an induction machine on the 50-period side, thus enabling the two sets to float on both systems without loading either supply with wattless current. The synchronous machine can be excited to such a degree as to give wattless current equal to or exceeding that taken by the induction machine connected to the same busbars. The first set consists of a 730-b.h.p., 600-r.p.m., three-phase, 50-period, 6,600-volt induction slip-ring motor rigidly coupled to a 500-kw., 0·8 power factor, three-phase, 40-period, 6,600-volt synchronous-type generator. The second set is similar except that the slip-ring induction motor is designed for 40 periods and the synchronous generator for 50 periods. Two liquid starters are provided for starting the induction motors, and two sets of resistance grids are permanently connected in series with the rotors of the induction motors to give approximately 1½ per cent additional slip at full load. The provision of slip-ring motors with adjustable permanent slip resistance provides, as it were, a flexible coupling between the two stations so connected. It is not necessary that the two stations should run in exact synchronism. The frequency of one station may vary approximately 2½ per cent in either direction without overloading the frequency-changer set. Suppose that the Tredegar station keeps exactly a frequency of 40 periods. If the machine at Oakdale were overloaded, the speed of the prime movers will have a tendency to drop, but in the measure that its frequency drops below 50 periods, one of the frequency changers will transmit power from Tredegar. If the drop be approximately 2½ per cent, then 500 kw. will be transmitted in that direction with one frequency changer running, and 1,000 kw. if both are in service. On the other hand, if the prime movers in Oakdale have a light load their speed will rise above the normal frequency, and power will be transmitted from Oakdale to Tredegar. The condition for the smooth working of the plant is, of course, that the governors of the prime movers in both the Tredegar and Oakdale stations should cause a few per cent drop in speed from no load to full load. This condition applies in general, as is well known, to prime movers driving alternators for parallel operation. The outside adjustable slip-ring resistance allows the slip of the frequency changer to be brought into line with the regulation of the governors in both stations. This would not be possible with squirrel-cage motors. The provision of slip-ring motors with starting resistances also simplifies the synchronizing of the sets.

Mr. Nelson.

Mr. Peck.

Mr. J. S. PECK (*in reply*): I quite agree with Mr. Chamen's remarks as to the great difficulties involved in changing over a large generating station from one frequency to another. In fact I have already pointed out that it is the difficulty of changing over the consumers' apparatus, rather than the provision of new plant in the generating station, that makes the substitution of one frequency for another almost impossible except in the case of quite small stations. I think, however, that where a station is isolated from other stations in the same district, due to a different frequency being used, the desirability of coupling two generators to one turbine is worth consideration when laying down new generating plant, one generator to be wound for the frequency of the station and the other for the frequency of the district. There are probably a number of generating sets the steam end of which is badly out-of-date while the generating

Mr. Peck

and is in good condition. These old generators could be used with new turbine plant for obtaining one frequency or the other. The advantage of a set with two generators is that it can be driven by the turbine and can supply current at either frequency or both ; or it can be used as a frequency changer to take energy from either system and supply it to the other.

Mr. Chamen and Mr. Nelson refer to a certain installation consisting of two frequency-changer sets of the induction-synchronous type. If this plant were being installed to-day, the two sets would probably be replaced by one double synchronous set.

Where two or more very large stations are connected together by short lengths of cable, I think it will be highly desirable to install reactance coils in the interconnecting lines, otherwise a short-circuit on any part of the system may produce serious disturbances and perhaps shut down all of the generating stations. In my introductory remarks I referred to a case of trouble due to surging where two stations a long distance apart were interconnected by cables having a small cross-section of copper. This matter was discussed at Newcastle, and will be found in the discussion already published in the *Journal*.*

Mr. Pec

Mr. New raises the possibility of earthing the neutral point of a generating station through a spark gap or some automatic device which normally leaves the circuit insulated but connects it to earth in the event of trouble. I do not think such devices are usually very reliable, and I believe it is much better to earth the neutral point through a resistance, especially where balanced protective gear is used.

With regard to the Scott system of connection for changing from three-phase to single-phase, this will not give a balanced load on the three-phase circuit unless the two single-phase circuits are equally balanced. This then becomes in effect a two-phase system.

Mr. Kinsey has given some interesting information with regard to the effect of earth currents on telegraph and telephone circuits. There seems to be a very great difference of opinion as to what currents can be transmitted through the earth without interfering with these circuits, and it would be interesting if someone could give definite information as to what currents and frequencies can be safely transmitted.

With Professor Robertson's remarks I am in general agreement, and am much obliged to him for the diagrams which he has submitted.

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* See page [illegible].

TELEGRAPH POLES IN NEW ZEALAND.*

By J. ORCHISTON, Member.

It is now over 50 years since the first telegraph lines were commenced in New Zealand, and by 1866 telegrams could be sent from Wellington to the Bluff. As wooden poles were used for the bulk of the early lines, sufficient time has now elapsed to enable one to form a fair judgment of the lasting powers of the different classes of timber used under the varying conditions involved.

The first lines erected simply consisted of bush saplings of the required dimensions with the necessary attachments of wire, arms, and insulators, no preference being shown to any one class of timber. In fact it might be said that the early engineers had no prejudices. The only tree which seemed to be barred was the cabbage tree. During the years 1864, 1865, and 1866 more attention appears to have been devoted to charring the bases of the poles than to the class of timber used. In spite of all the charring with its attended extra expense, some poles commenced to fall down within two years of their erection. In 1867 it was decided to restrict the timbers to totara (*Podocarpus totara*) and matai (*Podocarpus spicata*) and to have the poles sawn from fully matured trees if possible. The system of charring the butts, however, was continued until repealed by the then general manager of telegraphs, the late Dr. Lemon, who considered the cost of charring to be too much for any advantage likely to accrue. Subsequent events proved the wisdom of this decision.

In 1867 the line from Wellington to Masterton was erected with sawn heart of totara and matai—a fair proportion of each. The contractors had to char all poles for the first 7 ft. from the butt before erection, and if my memory does not deceive me, the extra cost for charring was 7s. per pole. Within six or seven years of erection some of the matai poles began to fall down in spite of the charring, which from an old-country point of view, had always been looked upon as a sure means of preserving timber in the ground. Before 10 years had elapsed the poles, both totara and matai, commenced to come down by the run whenever the wind blew a little more strongly than usual. In 1877 it was decided to repole the section, Wellington to Masterton, practically throughout. With few exceptions all the poles along the Hutt Valley and Wairarapa Plains were replaced with new poles, the old ones being chopped down. While this work was being carried out it was discovered that the poles along some three miles of the line over the hills at the Silverstream had not been charred. The reason for this has never been fully cleared up. It may be sufficient, however, to remark that this portion of the line passed over very rough ground and the poles were well out of sight of any one traversing the road along the river bank. The point I wish to draw attention to, however, is the fact that all the uncharred totara poles were found to be perfectly sound in 1877, whereas practically all the charred poles were more or less affected with dry rot. Near the Pakauratai another portion of the line was erected well back from the road. These poles had also escaped being charred and were found to be as sound as on the day they were erected. In 1868 and 1869 the line from Wellington to Wanganui was erected entirely of totara poles, and in 1877 and 1878 this line was thoroughly overhauled and only one bad pole found, but there were no charred poles on this line.

The first line from Auckland to the Waikato, commenced in 1863, consisted of saplings, which began to fall down in 1866. In 1867 the erection of sawn heart of totara was commenced to replace the saplings, and 12 miles of these poles, carefully charred, were erected between Hamilton and Ngaruawahia. Within 10 years these poles began to give trouble. In 1868–9 the section from Auckland to Ngaruawahia was also repoled, but fortunately the poles were not charred. When this section was overhauled in 1880 only one defective totara pole was found in 70 miles; but in the next 12 miles from Ngaruawahia to Hamilton, practically all the original charred poles remaining were more or less defective. Similar experience respecting charred poles had been obtained in Otago. Some poles were also tarred with little better results. Owing to some rimu and other timbers being passed for totara between Mercer and Miranda in 1868, the Auckland totara got a bad name, as the poles on this section of line began to come down in 1871 and 1872. It was therefore decided to replace all defective poles with heart of kauri. The result was that all poles showing the least sign of rot were dug out and kauri poles erected in their place. In 1880 some of the kauri poles began to give trouble and I then personally inspected this section and discovered that all the original poles had not been totara and that some good totara poles had been dug out because of sap on one or two corners having rotted. Nine of these poles which had been condemned and thrown out eight years previously were again brought into use and some of them may be standing now. The passing of rimu and other timbers for totara in this case was the means of condemning the use of the local totara timber in the Auckland province for telegraph poles for eight years, and resulted in the use of some 10,000 kauri poles. In clearing the line in one case, first-class totara trees were felled and left lying under the wire, whereas kauri poles had been dragged some miles over a very difficult bush track to support the line. Subsequent experience has proved that totara on the average has at least double the life of kauri.

At one time it was considered that the poles should be well seasoned before erection, and thousands of poles were stacked for seasoning purposes and to be ready for emergency.

In 1880 I had a number of the short-length totara poles replaced with longer ones between Auckland and Drury where the wires required raising. As some of the kauri poles between Auckland and [illegible] erected in 1873 had been giving trouble, the short totara poles removed from the [illegible] line were cut into three pieces and used for butts, by being placed some 4½ ft. in the ground alongside the defective kauri poles and bolted to them. In 1885 one of the kauri poles with a totara butt fell down. A careful examination of these poles and butts was then made, and it was discovered that in many cases the kauri poles were actually holding up the totara butts, instead of the latter supporting the pole. It was, however, only the seasoned portion of the original totara pole which had rotted, the portion which had been in the ground south of Auckland for some 12 years and another five years supporting the kauri pole was still good, whereas the next two sections of the same pole were, in most cases, seriously affected with dry rot. This was another discovery, viz. that seasoned timber was not so durable as unseasoned when placed in the ground. It is almost needless for me to recapitulate the dozens of other experiences pointing to the same conclusion. I may, however, give one or two other illustrations. The Wesleyan Mission built a church at Mangungu, in Hokianga, about the year 1835 and abandoned it in 1845. The front fence, some three chains, consisted of hand-sawn totara posts 5 in. × 4 in. When I viewed the fence in 1883 the posts, with the exception of two which were missing, were all perfectly sound. I tried to break one down to bring it away as a relic but was unable to do so. The rails had apparently been kauri and had rotted away, and only in one case was there a small piece hanging to a post. As the posts had been cut from trees growing alongside, it is evident they had not had much seasoning before erection. It might also be here noted that the church was built of totara and early in the eighties it was found to be in such a good state of preservation that it was taken down and re-erected at Kohu Kohu for a town hall, in spite of its having been unused and uncared for during the previous 36 years. I am advised that the building is still in use.

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* Paper read before the Institute of Post and Telegraph Engineers, Wellington, New Zealand, 30 July, 1914.

In 1870 a supply of totara poles was obtained at Havelock for the Naseby line. It has been said that when the schooner arrived at Havelock some of the poles were still growing. Immediately the schooner reached Waikouaiti the wagons commenced loading up, and within a few weeks from the time the poles were growing trees, they were carrying the telegraph wire.

Owing to portions of the old road being abandoned, and the inaccessibility of the line, it was decided five years ago to move some 35 miles of line passing through Naseby to Wedderburn. When dismantling this line it was found that the bulk of the poles which had been erected 38 years were still in first-class condition, and some 85 per cent of them were re-erected. I, however, took the precaution to bolt a short length of old railway rail at the base of each of the old poles; by this means I [illegible] they will be good for another [illegible] years.

I have already mentioned the fact that the first lines were erected with saplings, no attention being paid to the class of timber. This gave valuable information, as it was soon discovered that the life of Kahikatea saplings was only about two years, rimu little better, manuka from three to four years, [illegible] saplings about the same as manuka. Only the sap of [illegible] and [illegible] had had time to get before the heart of these poles were cut down to make room for the uniform system next adopted of sawn poles from matured trees. My experience, extending over a period of 37 years, in the engineering branch has, however, satisfied me that the heart wood of young trees is much superior to that of older trees, and this especially applies to both totara and matai. The only trouble is that there is such a large percentage of sapwood on the young trees. I have here a few samples of the sapling poles which I saw being felled in Inch Clutha in 1864. The land where these trees were grown is exceptionally rich, being a portion of the delta at the mouth of the Clutha River. As the order had gone forth that all sapling poles had to be replaced with sawn heart of totara, the life of these poles was cut short by means of an axe in 1871 after they had done duty for some seven years. In 1903, 39 years after erection, I had these samples dug out. Some 6 in. were showing above ground, so that no better test could have been applied. It will be observed that the totara sapling had only had about 1½ in. of heart wood, and as these poles had to be 9 in. at the base, it will be seen that this had been a very young tree and had grown on rich land, otherwise the heart wood would have borne a relatively larger percentage of the whole. I draw special attention to this, because 19 out of 20 people one meets are of opinion that timber should be obtained from well-matured trees and grown on hilly land. From my previous experience of totara I was not surprised to find the heart of this sapling sound after being 39 years in the ground; in fact I should have been surprised had it been otherwise. What did surprise me, however, was to find the matai in even a better state of preservation, as all our experience hitherto had been that the life of sawn heart of matai poles was limited to about 10 to 12 years, and even less in many cases; whereas here was a case of saplings grown on land as rich as any in New Zealand with only some 4 in. heart timber standing 39 years at the ground-level without the slightest sign of decay. Of course it must be clearly understood I am referring to the heart timber only; the sap of any of our timbers in-so-far as lasting in the ground is practically worthless; from two to three years might be said to be its life whether on young or old trees. I have often heard it said that the timber should be cut down in the winter. I cannot say whether or not there is anything in this. I have never been able to gain any proof for or against the argument; theoretically, seeing that our trees are evergreen, I do not see that it matters much when they are felled. What is much more important is the class of ground the timber is placed in. Light soils liable to become alternately wet and dry are the most trying, no doubt because such soil admits of the partial seasoning of the timber and thus brings about a similar condition to that of seasoning before erection. Wet, heavy, clay land is the best. To obtain the best results, timber must be kept as nearly as possible either wholly wet or wholly dry. It is the frequent changes between wet and dry which bring about premature decay, and of course this is the most pronounced an inch or two under the surface of the ground. To sum up, if one wants totara poles, blocks, or posts to outlast oneself it is necessary to see that they are placed in the ground as soon after felling as possible; also the timber from old or dead trees, or burnt bush, must not be used.

Before concluding my comments on wooden poles I think it is worthy of note that a retired inspector of telegraphs from Western Australia, a Mr. Priece, whom I met at Rotorua recently, said that his experience was that jarrah should not be seasoned before being placed in the ground. He volunteered this information before I mentioned anything about my having similar experience with New Zealand timbers. Needless to say, I was delighted to have this corroboration of my experience from such an unexpected source and one that could be thoroughly relied upon.

The first genuine attempt to prolong the life of poles in New Zealand was made under my directions in Auckland in 1880. The method adopted was to insert a fresh piece of timber principally totara or puriri alongside of the defective pole, bolting both together. These pole butts, as they were called, were from 7 ft. to 10 ft. in length, and varied from 6 in. to 10 in. square according to the size of the pole to be supported and whether an angle or a straight-line pole. I should here point out that our poles were all sawn or hewn square and that the butts were of similar square dimensions; hence the facility for making a solid job. Where poles are very far gone a second butt is usually attached in such a manner that one butt is in line and the other at right angles; by this means the bolts, which are usually from ½ in. to ⅝ in. diameter, cross each other a few inches apart and thus prevent any risk of the pole splitting at the butt after it has rotted off at the ground line. In some cases the original pole has rotted away at the ground line and, being supported by two butts, each of equal strength to that of the pole itself, is really a stronger structure than when first erected. These butts are usually inserted from 4 ft. to 5 ft. in the ground with 3 ft. to 4 ft. out (the angle butts and those supporting large poles somewhat deeper). The bottom bolt should be about 9 in. above the ground line, and the top bolt 3 in. to 4 in. from the top of the butt. The principal objections to these wooden supports are the liability to catch fire in a scrub country where fires are frequent, and that being wood they will rot in time in a similar manner to the pole itself. A far better method, and one which I adopted in Otago some time ago, is to use short lengths of discarded railway rails for the purpose. All railway services accumulate a large quantity of short lengths of rail. The most suitable for our purpose are from 7 ft. to 9 ft. in length, and these usually cost about £2 10s. per ton and can be frequently obtained in the neighbourhood where wanted. By this means the life of a wooden pole can be indefinitely prolonged at a cost of from one-sixth to one-tenth of the cost of replacing it with a new pole. The usual class of rails obtainable in New Zealand weigh 40 lb. and 53 lb. to the yard—a very suitable size for butting small poles up to 25 ft. in length. Heavier rails from 90 lb. to 100 lb. per yard are better for supporting large poles up to 35 ft. or 40 ft. in length. For such poles the butts should be 9 ft. to 12 ft. in length, and even longer for sharp angles carrying a large number of wires. Of course angle butts should be placed against the front of the angle, and where necessary two rail butts can be inserted side by side if the pole is a square one of fair dimensions. The angle pole can be held back by means of block and tackle while the butts are being placed in position.

As the supply of short lengths of rail, in fact any class of old rails, has not been equal to the demand in New Zealand for some time, I have had some hundreds of tons of heavy rails, from 7 ft. to 30 ft. in length, imported from Australia for the purpose, with first-class results. I may be wrong, but in my opinion this method of prolonging the life of wooden poles is far ahead of anything I have heard of elsewhere. These rail butts can be as readily attached to round poles, but in this case instead of placing the flat base of the rail against the side of the pole, with the bolts passing through the flange of the rail, the butt should be placed side on to the pole so that the curve of the pole will partly fill the cavity between the crown and the base of the rail. In this case the bolts will of course pass through the web of the rail. Portable, hand drilling-machines are generally used for drilling the holes in the rails, whether through the flange or the web as may be required. Care should be taken to see that the first butt attached to a pole shall be so placed that the main strength of the rail will be so applied as to support the pole from cross strain. If not carefully watched some linemen and even foremen are liable to disregard this and to place the rail with its most effective strength up and down the line, thus obtaining only about one-third of the carrying capacity in the direction most in need of support. These rail butts need not be inserted until the pole shows signs of decay. There are some totara poles well over 40 years old without butts, but as the timber becomes more brittle the longer it stands, it is as well to attach a rail butt to all poles after they have stood for, say, 30 years. In many cases poles require butting much sooner according to the class of ground where they are erected, or if they had been seasoned any time before erection, as previously pointed out.

The plan of attaching rail butts as indicated has several advantages. For instance, when a foreman is examining the line he is continually coming across poles which cause him a good deal of thought as to whether the pole should be replaced or not. When these poles can be cheaply secured by means of a rail butt he has less reason to worry, and should so secure all poles he has the least doubt about, as the first essence of a telegraph service is freedom from interruptions. I have had thousands of poles secured by means of rail butts and I have not known a single failure. Many thousands of pounds have been saved to the country by this means, and, no doubt, greater savings will still be made in future.

The first iron-rail poles were erected by my predecessor, the late Mr. Logan, between Dunedin and Seacliff in 1878. This system of using discarded railway rails has been largely adopted in New Zealand ever since. Our principal trouble, however, is that we cannot get enough of them. When properly constructed the rail-pole lines give first-class results and are no more costly than their equivalent in wood, with the advantage that they are lasting, especially the old iron rails which were used before the advent of the steel rail. Like the old telegraph wire of 40 and 50 years ago the old rails are far superior from a durability point of view, compared with the steel rails of recent times.

This paper would not be complete without reference to the latest development, viz. reinforced-concrete poles. Over 3,000 of these poles have been manufactured already for the Department, varying from 25 ft. to 35 ft. in length. About 1,000 have been erected between Auckland and [illegible], and a few elsewhere. So far they have proved a [illegible] and their use will doubtless be greatly extended in the future, as there is every reason to believe that their lasting properties will far outreach those of any other class of pole; in fact they will improve with age instead of deteriorating. The chief objection to their extended use is on account of the extra weight involving increased transport charges and erection expenses. In fact they can only be considered for use along good roads or adjacent to railway lines. Another feature is that owing to the rapid expansion of our telephone business it is difficult to know exactly what height of poles will be required in any locality a few years hence, and owing to the greater weight of these poles it will not be an easy matter to remove them elsewhere should they become too small for the number of wires to be supported. Consequently, seeing the greater prospective life of these poles, it would not be good engineering to sail too close to the wind from a carrying-capacity point of view. This brings one back to the £ s. d. question. As these poles are somewhat dearer than the equivalent in wood or iron, apart from the added cost of transport and erection, and if a greater margin of capacity is provided for so that they may not need to be replaced with larger poles for some considerable time, the gross outlay becomes still more pronounced. Still there is room for their use in many locations, especially where stability is a prime consideration, for instance, along our main telegraph routes. It is proposed to use a considerable number from 30 ft. to 35 ft. in length for replacing smaller and defective poles along the main line between Wellington and the Wairarapa. Some of the 35-ft. poles weigh nearly two tons; it is therefore obvious that the question of transport and erection is no light one.

I may perhaps have wearied you somewhat with these semi-historical details, but as I am practically the last of what might be termed the "old school of telegraph engineers," I have thought this summary of events and experiences may be of interest, not only to the present generation, but to those who will come after us.

PROCEEDINGS OF THE INSTITUTION.

595TH ORDINARY MEETING, 8 FEBRUARY, 1917.

Mr. C. P. **Sparks**, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on the 11th January, 1917, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and it was ordered to be suspended in the Hall.

Messrs. H. Honey and E. R. Myers were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Member.

Albertus, Christian Vilhelm G.
Andersen, Anders Christian M.
Westergaard, Paul, Capt., Danish R.E.

Associate Members.

[illegible]
d'Andria, Austin Vivian, 2nd Lieut., R.E.
Geipel, Kenneth Shute.
Greenhalgh, Frank.
Harrington, James.
Hilling, Alfred George.
Maunder, Henry Norrish.
Mundy, Alfred William H.

Graduates.

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
White, Alfred.

Students.

Anderson, Norman Leonard.
Codd, Edward J.
Finch, Percy Rupert C.
Forster, Harold John.
Heatly, William Gladstone.
Iudkevitch, Raphael.
Khan, Abdul Hamid.
Luboshez, Benjamin Ellan.
Luboshez, Sergius N.
Melides, Ermeneos.
Pollard, Harry Hendy.

TRANSFERS.

Associate Member to Member.

Allen, Claude.
Bridge, Norman Cressy.
Browne, Oswald Henry.
Lang, William.
Nicholson, John Steel.
Webber, Oswald Thomas O'Kelly, Capt., R.E.

Associate to Member.

Malek, Esmond Morgan.

Graduate to Associate Member.

Smith, Allen Egbert.

Student to Associate Member.

Corlett, Thomas Arthur.
[illegible]
Holttum, Worsley.

Student to Graduate.

Adams, Arnold William.
[illegible] T.
Hall, Percy [illegible]
[illegible]
Mansell, Harold Leslie.
Pant-Vaidya, Mahadev Vaman.
[illegible]
[illegible], Harold Edward

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : H. Alabaster, P. F. Allan, G. F. Allom, The Associated Municipal Electrical Engineers of Greater London, A. H. Bate, S. Beeton, I. Braby, F. C. E. Burnett, H. C. Channon, R. A. Chattock, W. Church, F. W. Clements, W. C. Clinton, The Hon. E. Cozens-Hardy, I. S. Dalgleish, J. D. Dallas, F. R. Davenport, B. Davies, F. E. Davies, B. Dennis, Sir A. Denny, Bart., J. Devonshire, B. M. Drake, Dr. C. V. Drysdale, W. Duddell, F.R.S., K. Edgcumbe, L. H. Euler, E. Garcke, V. W. Gill, G. F. C. Gordon, Dr. R. T. Glazebrook, C.B., F.R.S., B. B. Granger, F. E. Gripper, C. W. Gwyther, H. T. Harrison, C. C. Hawkins, W. C. C. Hawtayne, Killingworth Hedges, D. Henriques, J. S. Highfield, H. Hirst, H. C. Holroyd, R. H. F. Houstoun, The Institution of Railway Signal Engineers, E. S. Jacob, Dr. G. Kapp, A. C. Kelly, W. T. Kerr, H. W. Kolle, A. E. Levin, J. R. P. Lunn, Sir Henry Mance, C.I.E., W. Mead, J. W. Meares, S. W. Melsom, C. H. Merz, L. B. Miller, W. M. Mordey, W. M. Morrison, W. C. Mountain, A. J. Newman, Colonel A. M. Ogilvie, C.B., C. Oliver, Major W. A. J. O'Meara, C.M.G., E. Parry, H. Parry, The Hon. Sir C. A. Parsons, K.C.B., F.R.S., W. H. Patchell, C. C. Paterson, F. G. Payne, W. Pintner, A. H. Preece, Ll. Preece, N. Prentice, H. Faraday Proctor, G. S. Ram, H. A. Ratcliff, W. R. Rawlings, T. Rich, R. Robertson, S. R. Roget, S. A. Russell, S. G. C. Russell, E. Seddon, A. Siemens, J. F. Shipley, H. A. Skelton, Sir John Snell, C. Stewart, A. J. Stubbs, H. W. Sullivan, E. E. Tasker, C. H. R. Thorn, A. P. Trotter, T. C. T. Walrond, S. L. Wong, W. B. Woodhouse, J. H. Woodward, C. H. Wordingham, H. E. Yerbury, and W. Young.

Building Fund : V. W. Gill, H. Hirst, Admiral Sir Henry Jackson, R.N., G.C.B., K.C.V.O., F.R.S., W. M. Mordey, Professor J. T. Morris, Sir John Snell, S. L. Wong, and H. W. Young.

Library : The Association of Supervising Electricians, Associazione Elettrotecnica Italiana, The Bombay Fire Insurance Association, The British Electrical and Allied Manufacturers' Association, The Canadian Department of Mines, The Canadian Government Trade Commissioner, The Director General of Posts and Telegraphs in Calcutta, A. E. Gott, W. G. Goudie, W. Heinemann, The Japanese Imperial Department of Communications (Electrotechnical Laboratory, Tokio), Messrs. Longmans, Green & Co., W. H. Molesworth, H. Sherley-Price, Messrs. E. & F. N. Spon, Ltd., The United States Department of Commerce.

The PRESIDENT : I have to announce that, in response to an appeal from the Engineering Standards Committee, the Council have made a special grant of £500 to enable the Committee to enlarge the scope of its activities (see page 240).

I have also to announce that the Council have decided to purchase on behalf of the Institution £5,250 of the new 5 per cent War Loan, and that the Benevolent Fund Committee are taking up £700 of the Loan. This is in addition to the conversion of holdings of the last Loan.

A paper by Mr. R. Townend, Associate Member, entitled "Frequency Changers" (see page 197) was read and discussed, and the meeting adjourned at 9.10 p.m.

INSTITUTION NOTES.

GRANT TO ENGINEERING STANDARDS COMMITTEE.

In addition to its annual contribution towards the [illegible] of the Engineering Standards Committee, the Council have made, in response to an appeal from the Committee, a special grant of £500 towards the cost of translation of the British Standard Specifications into French, Spanish, and Russian, and towards the expenses of the local committees which the Committee propose to set up in some 12 foreign and British Overseas countries to influence the adoption of British Standards and to act in an advisory capacity to the Committee in London.

EMPLOYMENT OF DISABLED SAILORS AND SOLDIERS.

The Queen visited on the 21st February the classes at the Northampton Polytechnic, Clerkenwell, E.C., for giving a preliminary training to disabled sailors and soldiers as substation attendants (see page 53).

In the unavoidable absence of the President, the Institution was represented by Mr. C. H. Wordingham, Vice-President, and the Secretary. Her Majesty showed the greatest interest in the work that was being done, and made personal enquiries from each man as to his disablement and the progress he was making in his training. The Optical Workshops were also inspected.

The question of organizing similar classes in towns other than London is under consideration by the Committees of the Local Sections.

LECTURES.

[illegible] lectures at that Institution, Great George Street, [illegible]

12 March [illegible]	[illegible]	"Foreign Trade in its Relation to Investment of Capital."
[illegible]	[illegible]	"The Decimal System of Weights, Measures, and Coinage."
[illegible] at 5.30 p.m.)	[illegible]	[illegible] James Forrest Lecture)

ACCESSIONS TO THE REFERENCE LIBRARY.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Report of the Committee on Standardization of Special Threads for Fixtures and Fittings. Rolled threads for screw shells of electric sockets and lamp bases. Feb. 13, 1915. 8vo. 3 pp. New York, 1915

ASSOCIAZIONE ELETTROTECNICA ITALIANA. Norme per l'ordinazione e il collaudo delle macchine elettriche, compilate dal Comitato Elettrotecnico Italiano. Edizione 1916.—Simboli e notazioni per le unità delle grandezze.—Simboli per gli schemi.
8vo. 70 pp. Milano, 1916

BADGLEY, *Colonel* W. F. Electricity and its sources.
sm. 8vo. 254 pp. [illegible], 1916

BENNETT COLLEGE, THE. Electricity. Edited by professors of the Bennett College.
2 vols. in 8vo. Sheffield, 1916

Vol. 5. [illegible] "Instruments."

BERG, E. J. and Upson, W. L. Electrical engineering. First course. 8vo. 428 pp. *New York*, 1916

BROADBENT, F. Dynamos and motor attendants and their machines. 8th edition.
8vo. 227 pp. *London*, 1916

CASE, T. W. Preliminary notes on a new way of converting light into electrical energy. Read before the New York Electrical Society, June 14, 1916.
8vo. 12 pp. [illegible] 1916

CLINTON, W. C. Electric wiring. A primer for the use of wiremen and students. 5th edition.
sm. 8vo. 208 pp. *London*, 1916

COOMBS, R. D. Pole and tower lines for electric power transmission. 8vo. 280 pp. New York, 1916

ENGINEERING STANDARDS COMMITTEE. [Publications]. no. 75, 76, 77. folio. *London*, 1916

[illegible]

[illegible]

[illegible]

EXPOSITION UNIVERSELLE ET INTERNATIONALE DE SAN FRANCISCO. La science française.
2 vols. 8vo. *Paris*, 1915

FLEMING, A. P. M., and PEARCE, J. G. The principles of apprentice training, with special reference to the engineering industry. sm. 8vo. 216 pp. *London*, 1916

THE JOURNAL OF
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VOLTAGE REGULATION OF ROTARY CONVERTERS.

By G. A. Juhlin, Member.

(*Paper received 30 September*, 1916; *read before* The Institution 8 *March, before the* Manchester Local Section 13 *March, before the* Scottish Local Section 20 *March, and before the* Yorkshire Local Section 21 *March*, 1917.)

The importance of the rotary converter as a link in power distribution is constantly increasing, as well as the necessity of utilizing to the utmost the material at our disposal. In order to obtain the best possible results at minimum expense, it is essential that the exact conditions of operation as regards voltage regulation and power factor should be known, and that the influence of the one upon the other should be clearly understood.

The limitations of the rotary converter with respect to voltage regulation are, of course, generally known, as well as the means adopted for obtaining the regulation, but the influence of the different methods on the converter itself, and on the system on which it operates, do not appear to be fully appreciated.

With continuous-current generators, voltage regulation can be obtained without difficulty and without additional cost, but owing to the constant conversion ratio of the rotary converter, special means for regulating the voltage are necessary whether the range of voltage is small or large. Small voltage variations are, however, obtained much more readily, and, as will be shown later, it is of great advantage to keep the range of voltage within the smallest possible limits compatible with the requirements of the service for which the machine is intended, as the difficulty and cost may be increased to a great extent by a few per cent extra regulation, which may bring the range outside the limit of one system and therefore necessitate the adoption of a more costly arrangement.

Several different schemes have been devised for the purpose of voltage regulation, but, of these, only two have found extensive use in this country. They may be described by their characteristic features as follows :—

(1) Reactance control.
(2) Booster control.

Other schemes which have been used to some extent are :—(*a*) Voltage variation by means of tappings on the transformers used in conjunction with the converter. (*b*) By means of an induction regulator. (*c*) By special design of the field system, the poles of which are split up into two or three parts, the voltage variation being obtained by varying the excitation on certain parts of the poles. (*d*) A combination of reactance control and tappings on the transformer is sometimes used in cases where two different voltage ranges are required for lighting and tramway work.

In such cases, the transformers are provided with tappings for the most suitable voltage for either range, the intermediate voltages being obtained by reactance control, or in some cases by induction regulators.

Reactance Control.

It is well known that if the field of a rotary converter is not properly adjusted for the electromotive force supplied to the slip-rings, corrective currents are required which bring the field to its proper strength. The values of these currents depend upon the adjustment of the excitation, and may be very large if the field is too strong or too weak. Indeed it is possible to operate converters without any excitation, in which case the required field is produced entirely by the armature. If the field is too weak, the corrective wattless currents are leading with respect to the converter, but lagging in the line, and if too strong they are lagging in the converter and leading in the line. This feature of the converter provides means for varying the voltage at the continuous-current terminals with a constant E.M.F. of the supply by what is known as "reactance control."

If reactance is introduced in the line or in the transformer supplying a rotary converter, and wattless currents produced which flow through this reactance, the E.M.F. delivered to the converter slip-rings can be increased or decreased depending on the change in the field strength of the machine. This will be clear when it is considered that a leading current is 90° ahead of the load current, and therefore 90° ahead of the E.M.F. in phase with this current. The E.M.F. of self-induction produced by this [illegible] current [illegible] behind it and is therefore in phase with the E.M.F. supplied to the converter, thus increasing it.

A lagging current is 90° behind the E.M.F. in phase with the load current, and as the E.M.F. of self-induction lags 90° behind the current producing it, it will lag 180° behind the supplied E.M.F., consequently decreasing it. Thus, if a reactance is introduced, the E.M.F. at the continuous-current terminals can be increased by strengthening the rotary converter field, and reduced by weakening the field.

It is clear that the wattless currents may be produced by varying the field current, in which case the voltage [illegible] independent of the load, or, if the voltage regulation is desired as a function of the load, the wattless currents may be produced by a series winding. The relations between the different electromotive forces are of considerable importance, and although generally known [illegible] Fig. 1 (A, B, and C) shows the diagrams of electromotive forces for different conditions [illegible]. The following notations are used in the diagrams:

I_a = A.C. load current.
I_w = A.C. wattless current.
X = Reactance in transformer and converter.
R = Total resistance of the circuit, i.e. transformer and converter.
Z = Impedance.

With unity power factor at the converter, Fig. 1 (A) shows the relations between the different electromotive forces.

A B is the electromotive force E_R desired at the continuous-current terminals reduced to equivalent slip-ring E.M.F.

B C denotes the E.M.F. due to the load current I_a flowing through the reactance X, and is equal to $I_a X$, and displaced by 90° from E_R.

C D is equal to $I_a R$ or the ohmic drop due to the load current, and is of course in phase with the converter voltage.

A D then represents the electromotive force E_R required on the high-tension side of the transformer, reduced to the slip-ring E.M.F.

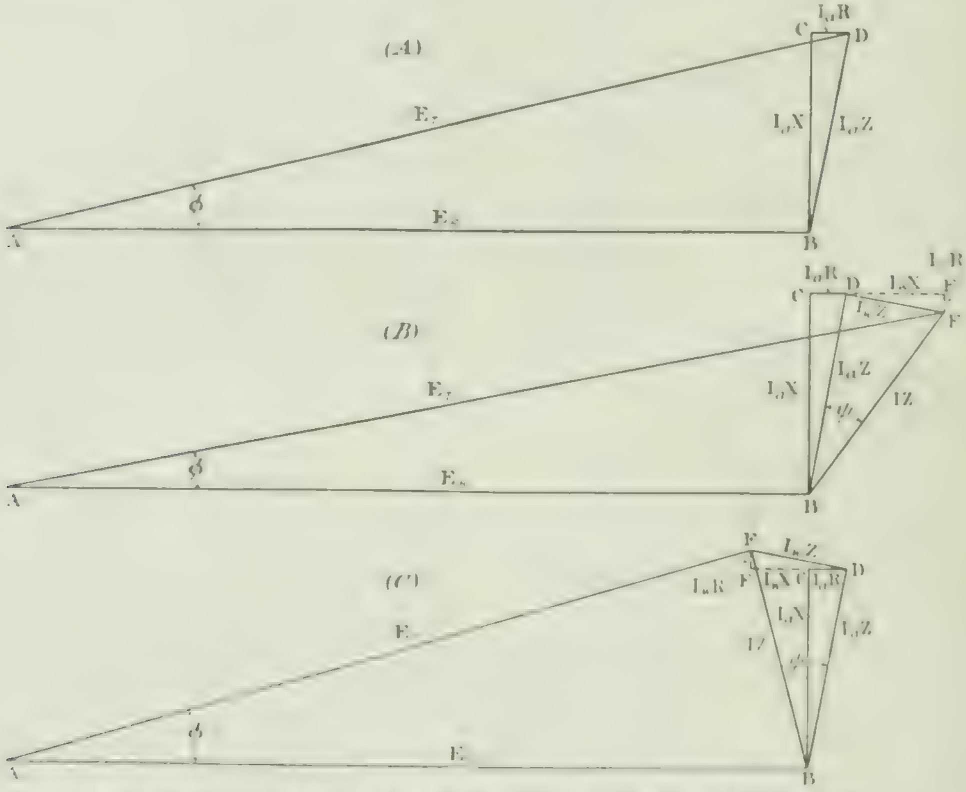


Fig. 1.—Diagrams of E.M.F.s of rotary converter with varying power factor.
A Unity power factor. B Lagging power factor. C Leading power factor.

If the power factor at the converter differs from unity, the relation between the impressed and delivered electromotive forces is somewhat more complex on account of the wattless current.

Fig. 1 (B) and Fig. 1 (C) are diagrams of the electromotive forces for the conditions of lagging and leading currents respectively.

A B is as before the equivalent voltage at the continuous-current terminals.

B C = $I_a X$, the E.M.F. due to the load current through the reactance, and C D = $I_a R$, the E.M.F. due to the ohmic drop.

B D is then the impedance drop due to the load current and is equal to $I_a Z$.

Referring to the electromotive forces due to the wattless current I_w, it is clear that the impedance E.M.F. due to this current must be at right angles to $I_a Z$. It consists of two components, $I_w X$ and $I_w R$. $I_w X$ is in phase with E_R when the power factor is leading, and in time phase with but opposing E_R when the power factor is lagging. $I_w R$ is displaced by 90° from $I_w X$. The electromotive force $I_w Z$ due to the wattless current flowing through the impedance is then represented by D F, and the electromotive force I Z of the total current flowing through the impedance by the line B F.

If the resistance and reactance are known, together with the transformer electromotive force E_T, $I_w Z$ and hence I_w may be obtained by taking A as the centre for a circle with radius E_T, and striking an arc intersecting a line at right angles to B D through D. $I_w Z$ is then given by the length of the line from D to the point of intersection.

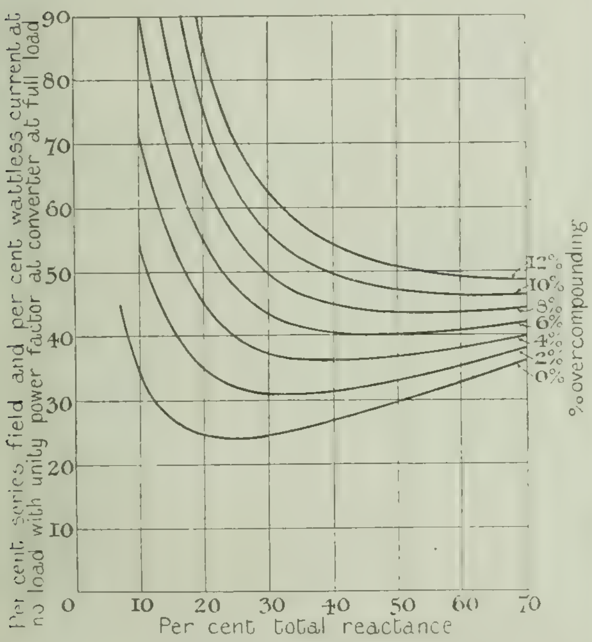


FIG. 2.—Curves showing relation between reactance and wattless current required in rotary converters for different amounts of over-compounding.

Resistance = 3 %.

If, on the other hand, a certain value of I_w is desired, E_T may readily be obtained by setting off $I_w Z$ on the line through D, in which case E_T is determined.

It may now be of interest to consider briefly the relations between reactance, resistance, and wattless current for different amounts of compounding.

In order to determine the most satisfactory value of reactance for a given compounding, it is necessary to know the change in wattless current with varying values of reactance.

The E.M.F. of the high-tension side of the transformer is assumed to be constant, and as the E.M.F. desired is fixed at no load and full load, an expression for the electromotive force E_T is easily obtained assuming the power factor at the converter to be unity at full load, from which the value of the wattless current is obtained. Fig. 2 shows the approximate relation between wattless current and reactance for different values of compounding. The curves are approximate in so far that the influence of saturation in the converter has not been taken into account. It would obviously not be possible to make allowance for this, owing to the very wide range over which it varies in different designs. The influence of the saturation on the compounding will, however, be discussed later. The curves are based on the assumption that the E.M.F. of self-induction of the transformer varies in direct proportion to the current. A total resistance drop of 3 per cent, including transformer and converter, has been assumed. This value will of course vary with the capacity and voltage of the machine under consideration, but may be taken as an average for ordinary outputs and voltages. The ohmic, as well as the reactance E.M.F. is expressed as a percentage of the no-load E.M.F., and the power factor has been taken as unity at full load. The curves may, however, be used without any appreciable error in cases where unity power factor is desired at any other load. In such a case the value obtained from the curves does not represent the wattless current at no load, but what may be termed the change in wattless current between no load and full load. For example, 10 per cent compounding with a reactance of 25 per cent gives 63 per cent wattless current at no load with unity power factor at full load. If, instead, it should be desired to obtain unity power factor at half load, the wattless current would be approximately half of this value, lagging at no load and leading at full load. The amount of series field required would therefore be approximately the same in either case.

Referring to Fig. 2, it will be seen that, except in cases of high percentage of compounding, the reduction obtained with increased reactance is very small when the reactance is higher than 30 per cent. Higher values than this are seldom met with in practice, as transformer builders are unwilling to build transformers having very high reactance, and the extra cost entailed in providing separate reactance is not compensated for by the small reduction obtained in the wattless current.

The question as to the point of the load at which unity power factor at the converter should be obtained, is of considerable importance. Large lagging currents can be carried by the converter at no load without difficulty, and, so far as the system is concerned, a lagging power factor is less objectionable at light loads than at heavy loads. If the lagging currents are large at no load, the leading currents required at full load or overload are reduced, which is advantageous for the converter as regards losses in the armature as well as the field copper.

For railway service it is usual to adjust the field so that unity power factor is obtained at three-quarter to full load. In general, it may be said that it should be at a point somewhat above average load, and, in making the choice, due consideration should be given to the extent and duration of overloads.

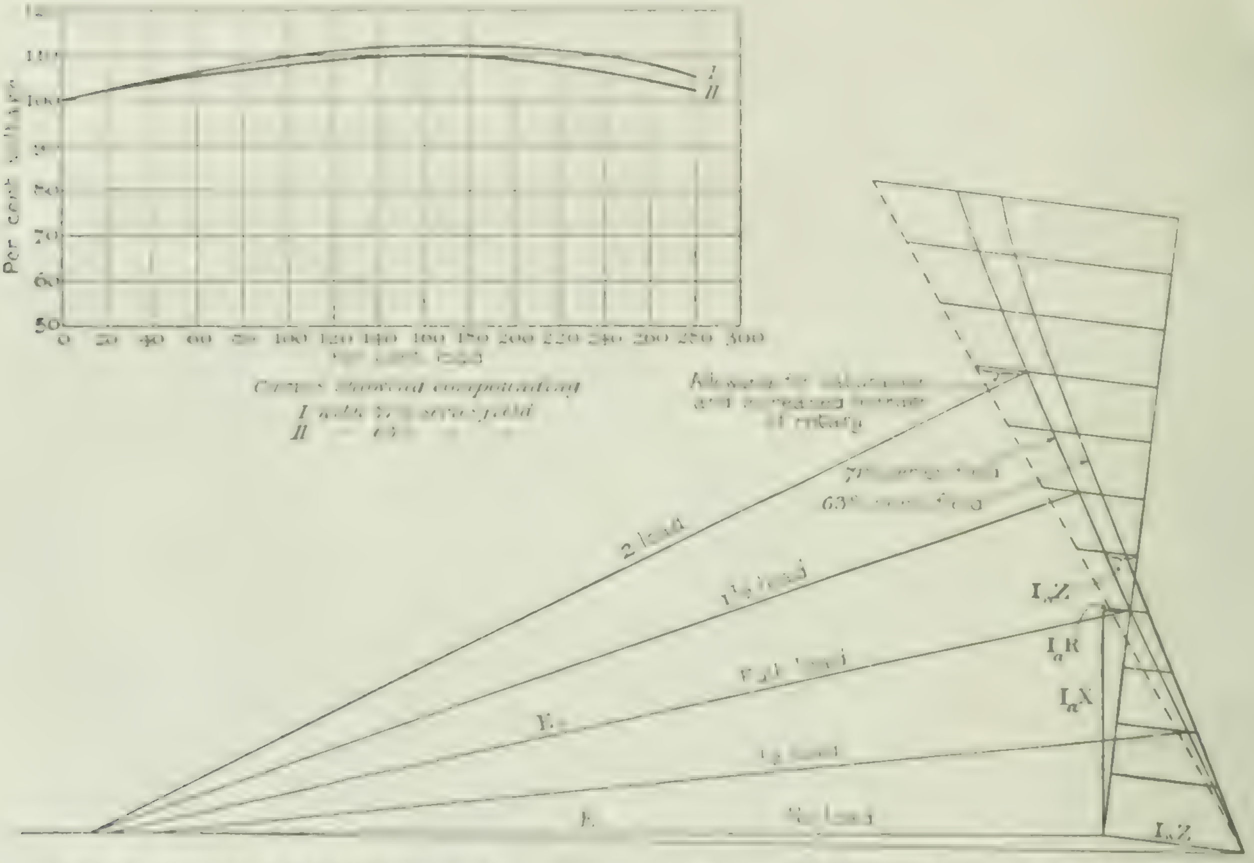
Low reactance and large wattless currents give, in cases where the saturation of the converter is low, better compounding on overloads than high reactance and small wattless currents, but in machines where the saturation is high the reverse may be the case.

The influence of saturation and leakage may be seen in Fig. 3, which shows the diagram of a [illegible] a converter, arranged for [illegible] per cent over-compounding from no load to full load. The total resistance drop of converter and transformer is taken to be 2 per cent and the reactance 15 per cent, assuming [illegible]. The power factor of the converter has been assumed to be unity at full load.

The wattless current required at no load would be 63 per cent of the full-load current, and consequently the ampere-turns of the series field would be 63 per cent of the [illegible] ampere-turns at full load, neglecting [illegible] ter. Owing to the saturation, however, the field strength required at the full-load voltage is [illegible] from the line. This would mean that the power factor would not be unity at full load, nor [illegible]

a diminution of the compounding. In the case under consideration, the increase in the series field amounted to 8 per cent, so that 71 per cent instead of 63 per cent would be necessary.

Another point which is of importance in machines with high saturation is that the leakage is increased when large leading currents are produced. This means that an increase in field current is required in order to produce the necessary flux; but as an increase is made in the field current, the result is a reduction in the amount of leading current produced by the series field and consequently in



[illegible] line characteristic.

the compounding. That the influence of saturation and leakage is by no means negligible is shown in Fig. 3 by the reduction in wattless current. The difference in compounding obtained with and without allowance for saturation is shown by curves I and II, Fig. 3.

The use of reactive iron in transformers, which is employed when a large amount of reactance is desired, has considerable influence on the amount of wattless current and series field required in order to obtain a given compounding, if the reactive iron is saturated, as in this case the E.M.F. of self-induction is not proportional to the current.

In order to show clearly the effect of saturated reactive iron upon the amount of series field required, and on the compounding, a transformer has been chosen in which the reactive iron is practically saturated at full load (saturation assumed to be reached at 22,000 C.G.S. lines); the reactance at this point is 25 per cent, but is 15·5 per cent at quarter load. The diagram of electromotive forces, together with the compounding curve, is shown in Fig. 4.

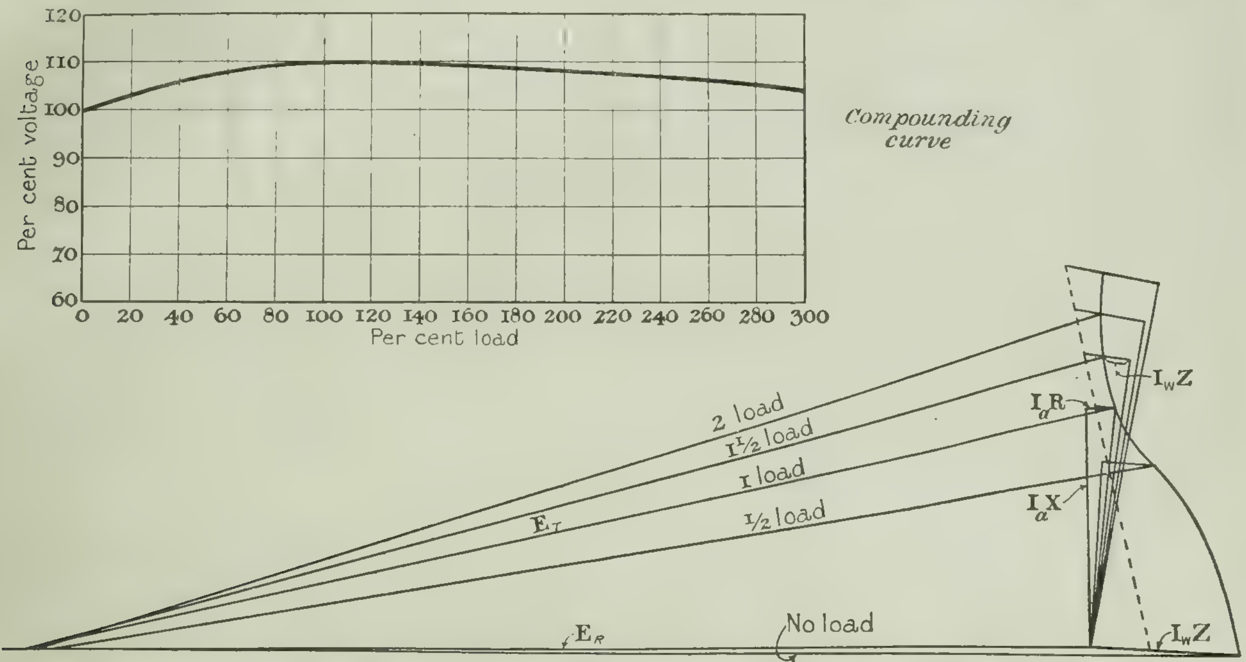


FIG. 4. Diagram of E.M.F.'s of compound-wound rotary converter; compounding by means of reactance.
Reactive iron saturated at about full load. Reactance at full load = 25%. Resistance = 3%.

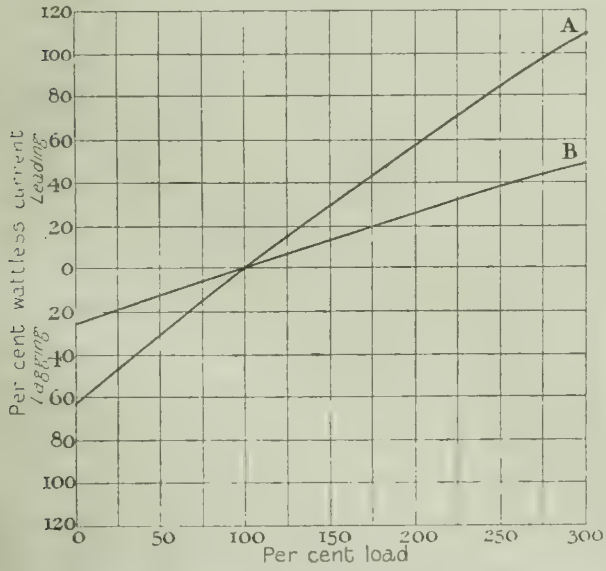


FIG. 5.—Curves showing wattless current required for 10% over-compounding; 25% reactance.

A. With straight line reactance and 71% series field.
B. With reactive iron saturated at about full load, and 33% series field.

The requirements as regards compounding are the same as in the previous case, and the transformer E.M.F. required is therefore also the same. The series field necessary to obtain the compounding is, however, much smaller, due to the high reactance at low currents; it amounts to 33 per cent, including the necessary allowance for saturation, as against 71 per cent with the straight-line reactance. The wattless currents at different loads are shown in Fig. 5, from which it will be seen that with saturated reactive iron at no load only 40 per cent, and at twice full load 45 per cent, of the value required with straight-line reactance are necessary. It will be noted from Fig. 4, however, that although the same percentage compounding is obtained at full load, the shape of the compounding curve is not as good. At light loads the voltage rises very rapidly and reaches a maximum at about full load.

Comparing this with curve I, Fig. 3, it will be seen that in this case the voltage reaches a maximum at about 100 per cent overload so that the regulation in this case is somewhat better. The difference is not great, and, in cases where the design of the converter permits the use of saturated reactive iron, the advantage would seem to warrant its adoption.

The difference in the shape of the compounding curve requires some consideration, owing to the unequal voltages obtained at different loads, as in extreme cases this may lead to difficulties as regards division of load between machines provided with transformers having different types of reactance.

In the case of voltage regulation being obtained by shunt control, the relations between the different electromotive forces of the converter and the transformers, all reduced to the equivalent secondary transformer E.M.F., are shown in Fig. 6.

The following conditions have been assumed for the case considered:—

Voltage regulation 15 per cent, i.e. ± 7½ per cent on either side of the mean.
Total reactance, 15 per cent.
Total resistance drop, 2 per cent.

The mean voltage required on the converter has been taken as the basis for the reactance and resistance, which are therefore expressed as a percentage of this voltage.

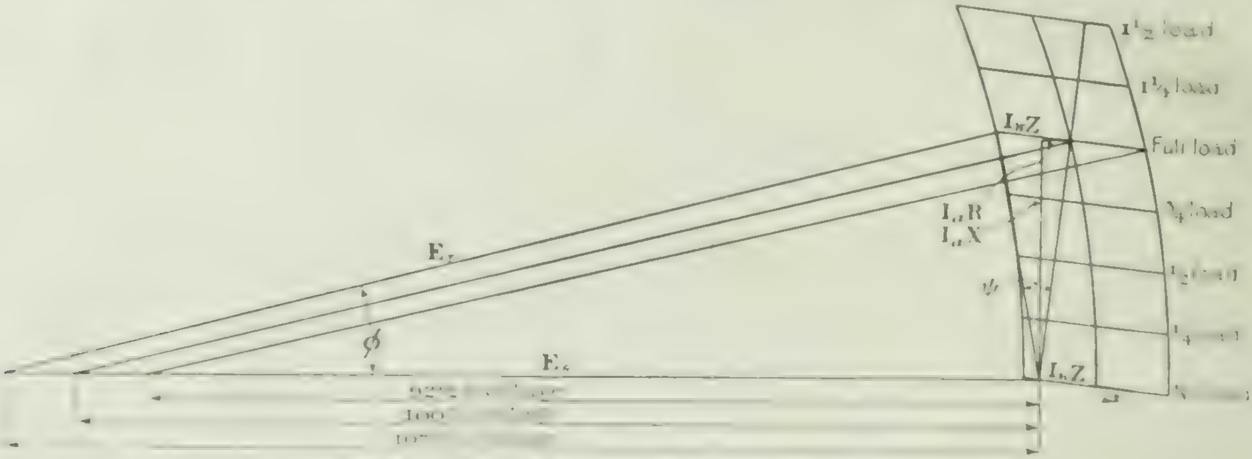


Fig. 16.—E.M.F. diagram of shunt-wound converter with reactance control.
Reactance [illegible]. Leading.

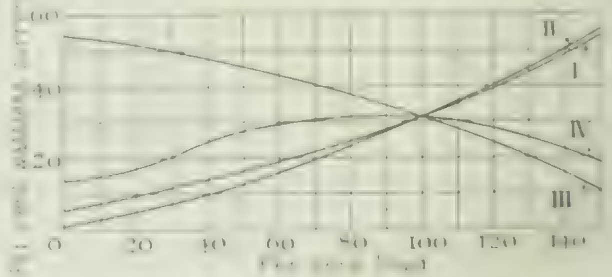
The amount of reactance must, as in the case of compounding, be determined by considerations of design of the converter, and also by the conditions desired for the supply circuit.

With any voltage variation, the value of the wattless current required with a given reactance depends on the conditions as to power factor desired on the high-tension side of the transformer. In the absence of any definite specification in this respect, the conditions most favourable to the converter are equal leading and lagging currents at the extreme voltages, as this will give minimum heating of the armature winding, which is a most desirable condition. This condition should be obtained at the maximum continuous load of the converter.

From the point of view of field heating, large leading currents are of course undesirable, but as it is generally possible to provide room for the field copper, this is not a serious factor in design. In the foregoing considerations, the wattless current has been proportioned for minimum armature copper losses at full load. Under these conditions the wattless current required at the high voltage will increase with the load, whereas at the low voltage the wattless current is a maximum at no load. The wattless currents required at different loads for the maximum and minimum voltages are shown in Fig. 17.

In the case of compounding it was stated that the wattless current and the series field required were reduced by the use of saturated reactive iron. With shunt control the wattless current required is practically the same from no load to full load and over, with straight-line reactance, as with saturated reactive iron. At these loads, however, a reduction in the wattless current is obtained by the use of saturated reactive iron. The advantage of this is very small, as the reduction of the wattless current is not of any importance so far as the converter itself is concerned. Some advantage as regards power factor is of course also obtained at the low loads.

It will be noticed that the curve giving the wattless current at the low voltage has a peculiar shape (see Fig. 17). This is due to the fact that the reactance is a function of the current, so that as the load decreases the reactance increases. The result is that although the reactance drop is increased the wattless current required is decreased, due to the higher reactance obtained when the total current through the reactance is low. It should be noted that the wattless current shown must necessarily be



approximate, as it is indeterminate and must be obtained by trial and error. This is specially the case at light loads where a small change in the current makes a great change in the reactance. From the foregoing it will be seen that there is no advantage, as far as the converter is concerned, in using saturated reactive iron, when the voltage variation is obtained by shunt control.

A possible disadvantage in connection with the rotary converter is that the saturated iron may cause sufficient distortions to the E.M.F. wave to make the corrective, higher harmonic, currents necessary to counteract these distortions objectionable from a point of view of commutation.

The question of power factor obtainable on converters, where voltage variation is obtained by reactance control, is of considerable importance from the point of view of both the designer and the operating engineer. It should be made clear at the outset that power factor correction cannot be obtained at will by a converter operating under these conditions, as it is a fixed quantity for a given voltage and load depending on the amount of regulation required, as well as on the point at which unity power factor is desired. The power factor at the converter for a given load is fixed by the amount of wattless current, leading or lagging, necessary to obtain the specified regulation. The power factor on the high-tension side differs, of course, materially from that of the converter itself, as the voltage on the primary side is displaced from that of the secondary side through the introduction of the reactance. Furthermore, the magnetizing current of the transformer affects the amount of wattless current on the high-tension side, increasing the current when lagging, but decreasing or increasing it when leading, depending on the relative value of the wattless current in the converter and the magnetizing current.

If the angle of displacement due to wattless current be ψ_1 we have

$$\tan \psi_1 = \frac{I_w \pm I_m}{I_a}$$

where I_m is the magnetizing current of the transformer.

The angle of displacement between the high-tension transformer E.M.F. and the E.M.F. delivered to the rotary is ϕ, which can be obtained from Fig. 1.

The power factor on the high-tension side of the transformer will then be—

Cos $(\phi - \psi_1)$ with leading current,
and Cos $(\phi + \psi_1)$,, lagging ,,

For the case under consideration, the power factor of the rotary converter and on the high-tension side of the transformer would be as follows :—

Voltage	107·5 %	100 %	92·5 %
Power factor at converter			
cos ψ	0·96	1·0	0·96
Power factor on h.t. side			
cos $(\phi \pm \psi_1)$	1·0	0·96 (lagging)	0·84 (lagging)

ψ being the angle of displacement of the currents at the converter. In arriving at these figures the magnetizing current has been taken as 5 per cent.

As already stated, the wattless current has been proportioned for minimum heating of the converter armature copper. It would of course be possible to proportion the wattless current so that a leading power factor is obtained at the high voltage with consequent improvement of the power factor at the low voltage. This would mean a considerable increase in the wattless current at the higher voltage, resulting in increased heating of the armature copper, and, as the current is leading, also increased field heating. At the overloads these conditions are of course accentuated. The power factor at light loads and low voltage would be improved, but the advantage obtained would not be very material from the point of view of either the converter or the supply system, as the heating of the converter is small at the low loads and the supply system is better able to deal with a low power factor at light loads.

In order to obtain unity power factor on the high-tension side at the mean voltage, 63 per cent leading current would be required at full load to reach the maximum voltage. If 100 per cent overload should be required at the maximum voltage, the leading current at this load would be 122 per cent, and the power factor at the converter would be 85 per cent leading. At the low voltage, the wattless current would be 58 per cent leading at 100 per cent overload, and the power factor 96 per cent leading at the converter. The difficulties in dealing with these large wattless currents will readily be appreciated when it is considered that the I^2R losses in the tap coils at 100 per cent overload, with 122 per cent wattless current, would be 3·1 times the losses at this load if the power factor were unity.

From the foregoing, the importance of reducing the voltage variation to the smallest possible value required for the service on which the machine is intended to operate will be appreciated, as well as the necessity of allowing the manufacturer a certain amount of latitude in regard to the specification of the power factor of a machine with a wide voltage variation. By careful consideration of the requirements as to voltage variation and power factor obtainable, it is possible to apply the reactance control up to fairly large variations in voltage without serious interference with the power factor.

In cases where two distinct ranges of voltage are required, a combination of reactance control and tappings on the transformer is capable of wide application, and deserves more consideration than it has received up to the present. In many cases pressures of 400 to 440 volts are required for lighting and 500 to 550 volts for traction. The following table shows the power factor at the converter and on the high-tension side of the transformer which can be obtained without excessive wattless currents. These currents are also given in the table :—

	Max. Volts 440	Mean Volts 420	Min. Volts 400
I_w	47% (leading)	26 % (leading)	6 % (leading)
Full-load power factor at converter—			
	0·9 (leading)	0·967 (leading)	0·998 ,,
Power factor on h.t. side—			
	0·99 (leading)	0·998 (lagging)	0·97 (lagging)
No-load I_w	22 % ,,	0 ,,	19 % ,,

For the 500- to 550-volt range, the wattless current can be kept within the same values as the above, and the power factor would therefore be approximately the same.

By increasing the leading current at the maximum voltage, it would of course be possible to obtain unity or even a leading power factor at the lower voltage, which may be of advantage in special cases.

The range of voltage variation obtainable with reactance control is limited on account of the excessive wattless currents required, and the low power factor resulting

[illegible]

[illegible] ± 7½ per cent [illegible] be obtained from Fig. 6. These values were based on the conditions of minimum heating in the converter, and the [illegible]

[illegible]

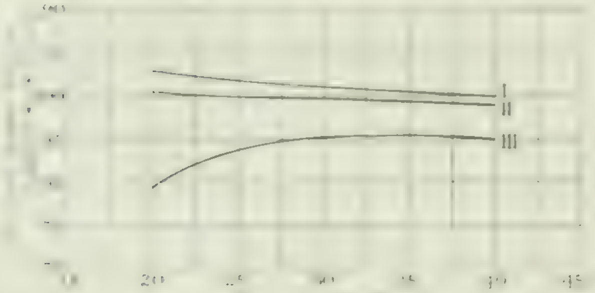
Full load [illegible]

Power factor at converter—

[illegible]

[illegible]

Considerably better power factors can be obtained by [illegible] depends on the particular design under con- [illegible]



[illegible]

wattless current can be carried. Fixing the limit at 55 per cent, and assuming as before a reactance of 25 per cent, the following table gives the results as regards wattless current and power factor at the different voltages :—

[illegible]

[illegible] tion considered is within the limits for practical [illegible]

[illegible] ent in power factor is [illegible] ing the increased difficulties in [illegible] in the transformer.

[illegible] improvement is obtained by increasing the reactance above 30 per cent.

In general, it may then be said that the limit of voltage variation, for which reactance control is applicable, is about ± 7½ per cent, but it should be noted that if the question of power factor is not of great importance, a greater range than this can be obtained with a wattless current of 55 per cent at full load.

A point of considerable importance in this connection is that it is possible to provide for a greater range in cases where the extreme limits are required for a short time only, as in the case of paralleling, due to the fact that larger wattless currents may be carried for short periods than would be the case for continuous operation. In such cases it may be of advantage to consider the reactance control for ranges which would otherwise be considered outside the limits as regards power factor and wattless current on the converter.

[illegible]

This method of voltage control is employed to a great extent for all classes of service.

As is well known, the voltage variation is obtained by the use of a synchronous booster mounted on the shaft of the converter. The type generally adopted is that with a revolving armature mounted between the converter slip-rings and armature. The field may of course be provided with shunt or series windings, or both, in accordance with the requirements of the service for which the converter is intended.

With the booster field unexcited and the converter operating on unity power factor, it is clear that the E.M.F. of the converter is not affected by the current passing through the booster, except to a very small extent, due to the impedance drop in the booster armature. This is, however, exceedingly small, as the ohmic drop is only a small percentage of the booster voltage and therefore negligible as far as the converter voltage is concerned, and the reactance drop is equally unimportant, being 90° behind the delivered E.M.F. The armature reaction is of course purely distortive, and has therefore practically no influence on the voltage.

When the power factor varies from unity, the conditions are, however, quite different, as the booster armature reaction is then either magnetizing or demagnetizing, and the booster armature magnetomotive force must therefore be balanced by an equal number of ampere-turns on the booster field. The booster field may therefore require a certain amount of excitation, although no change in the converter E.M.F. is required. Conversely it is possible to obtain boost, positive or negative, without exciting the field of the booster, by producing wattless currents in the converter which will produce the excitation of the booster. This feature may be of service in cases of emergency, such as when it is desired to put a converter into service and the busbar voltage has fallen below the lowest voltage obtainable from the converter under normal running.

From the above it is clear that the power factor is under complete control in a booster type of converter, as the influence of the wattless current on the E.M.F. can be counterbalanced by the excitation of the booster field. It should be noted, however, that it is essential not to operate a booster converter at a lagging power factor, as this will overload the booster field when raising the voltage, and may account for the booster not giving its full range of voltage.

The fact that the power factor can be kept at unity, or leading, if desired, is undoubtedly the chief reason why the booster type of converter has found such an extensive use. Some doubt may be expressed, however, as to whether this extensive use is altogether justified, as in many cases where comparatively small voltage variations are required, and the converter is not required to give wattless currents for power-factor improvement, the reactance control could be employed with equally good results.

The advantages of the booster converter are quite clear and well appreciated, whereas its disadvantages are not so apparent.

It is from the point of view of the designer rather than the operating engineer that the booster converter presents difficulties, but as the subject is of considerable importance it may be of interest to study briefly the influence of the booster on one of the most important characteristics of the converter, i.e. the commutation. As this point is of practical importance in the interpole type of converter, only this type will be dealt with.

In the simple converter all the electrical energy, except the small part absorbed in the losses, supplied on one side is transformed electrically and delivered in the form of electrical energy on the other side of the converter. The total armature reaction is in this case only produced by the losses in the converter, but the distribution over the pole-pitch is not uniform, with the result that a certain part is acting in the interpolar space. This must be compensated for by a certain number of ampere-turns on the interpole. The armature magnetomotive force is under these conditions a simple function of the load, and can therefore be taken care of by the ordinary commutating-pole winding excited by the load current.

When the booster is used, the effect of the converter armature is more complicated, due to the fact that a part of the electrical energy supplied to the converter is transformed into mechanical power and transmitted through the shaft to or from the booster, the direction depending on whether the boost is positive or negative. In the case of positive boost, i.e. when the E.M.F. of the converter is increased, it acts partly as a motor supplying mechanical power to the booster, which then acts as a generator in raising the E.M.F. On the other hand, when the converter E.M.F. is reduced by means of the booster the converter acts partly as a generator receiving energy from the booster, which is then operating as a motor delivering its energy through the shaft to the converter. Under these conditions the effect of the armature on the interpoles is no longer dependent only on the load of the converter, but also on the E.M.F. of the booster. This is due to the fact that the alternating and continuous currents are not balanced, as in the simple converter, and the converter armature therefore develops a motor reaction when the boost is positive, and a generator reaction when the boost is negative.

The value of this armature magnetomotive force is directly proportional to the output of the booster. For example, with the booster excited so as to raise the converter E.M.F. 10 per cent, the armature reaction would increase the interpole ampere-turns by an amount equal to 10 per cent of the alternating-current armature reaction, or, if the E.M.F. were reduced by the same amount, the interpole ampere-turns would be decreased by an amount equal to 10 per cent of the alternating-current armature ampere-turns. This would of course mean an increase or a diminution of the flux required to obtain correct commutation; and when it is considered that on the average the interpole ampere-turns necessary to produce this flux, as well as compensate for the normal armature reaction at zero boost, only amount to about 35 per cent of the armature ampere-turns, it will be readily appreciated that a reduction of 10 per cent means a big change in the strength of the interpole flux. In order therefore to keep the interpoles at their correct strength at any load and voltage, it would be necessary to provide some means whereby the interpoles are automatically adjusted with the load. It is of course also necessary to vary the excitation on the interpoles with varying boost.

Unfortunately, it is not possible to compensate the armature reaction completely, as it is not constant for all positions of the armature, but fluctuates to a considerable extent. These fluctuations exist in the simple converter as well as in the booster type, but are accentuated in the latter under certain conditions of boost.

Several different methods have been adopted in order to obtain the necessary compensation, all of which involve an auxiliary winding on the interpole, and in some cases special apparatus for varying the excitation of this winding. In most schemes the variation in the excitation is obtained by variation of the resistance in the circuit of the auxiliary winding, and the accuracy of the compensation depends therefore on the number of steps in which the resistance is changed. The question of rapidity in adjusting the excitation is of importance in cases where sudden load fluctuations occur, and the time lag must therefore be reduced to the smallest possible amount.

The problem of accurate compensation of booster converters is, as will be appreciated from the above, not an easy one, especially in cases where large voltage variations are required.

A certain amount of boost can, of course, be obtained without any adjustment of the interpole excitation, but it is very limited, and as the conditions of commutation cannot be made uniform for all voltages, it is clear that full advantage cannot be taken of the material if good commutation is to be obtained at all loads and voltages. In other words, a given machine would reach its commutation limit at a lower load, if fitted with a booster for voltage regulation, than would be the case if arranged for reactance control.

When inverted running is required and voltage variation is necessary, a booster is essential, if the converter is not running in parallel with any other alternating-current plant, as reactance control cannot be used in such cases. This will be clear when it is considered that, with a given condition of load to keep the speed, and therefore the frequency, constant it is essential to keep constant field current, assuming a fixed continuous voltage. In order to vary the E.M.F. delivered by the converter, it would be necessary, however, to vary the excitation, so that the two conditions are opposed. If the converter is running in [illegible] alternating-current system, it is possible to [illegible] voltage by means of reactance control, [illegible] the speed of the converter cannot [illegible] that it is tied in synchronism with the system to which it is connected. Inverted running should, however, be considered as an emergency condition, as the rotary converter is primarily a machine for transforming alternating current into continuous current, and not vice versa.

The influence of the booster on the losses in the armature winding is of some importance and interest. The relations between the armature losses in a non-booster converter, and that of a continuous-current generator with

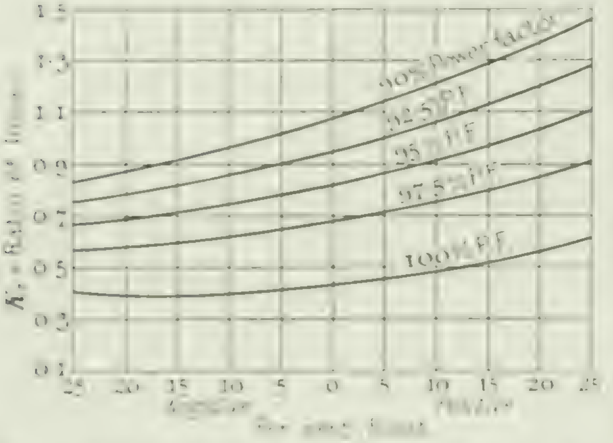


Fig. 9.—Curves showing ratio of I² R losses in the tap-coils of a six-phase rotary converter to those of a continuous-current generator with a similar winding.

the same winding, have been established for different power factors, both for the tap coils and for the whole winding. These ratios do not hold good, however, when a booster is introduced, as the resultant current in the armature winding varies for different values of boost. That this is the case will be clear when it is considered that the ratio of transformation of the converter is changed by the action of the booster. The values of the constants giving the ratios of the losses for different percentage of boost and power factor are shown in Figs. 9 and 10, the former giving the ratios for the losses in the tap coil and the latter for the average losses of the whole winding.

The derivation of the formulæ by which these curves have been computed will be found in the Appendix. An interesting feature brought out by these curves is that the constants giving the ratio for the tap-coil losses, as well as for the average losses, increase with positive boost but decrease with negative boost until a certain value of negative boost is reached, after which they will be found to increase again.

The fact that the losses in the tap-coils decrease with increasing negative boost is of practical importance in [illegible] output is required at the low voltage, [illegible] the heating of the tap coils is the limiting feature [illegible] copper heating of the armature [illegible] current [illegible] in the armature copper will be [illegible] where the voltage variation is obtained by means of a booster than would be the case if other means were used.

If the whole range were obtained by negative boost, a considerable reduction in the tap-coil losses would be obtained at the low voltage, but owing to the increase in the output of the booster, the cost of the converter would in most cases be increased.

The reduction in the losses obtained in ordinary cases is, however, of importance, especially in cases where the converter has to deal with wattless currents for power-factor correction.

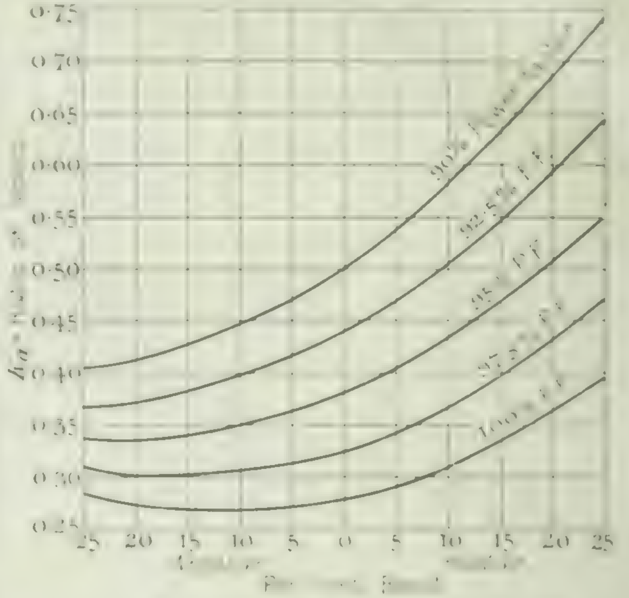


Fig. 10.—Curves showing ratio of average I² R losses in armature winding of a six-phase rotary converter to those of a continuous-current generator with a similar winding.

COMPARISON.

No general statement as to which system of control is most advantageous can be made, as this must naturally depend on the conditions of the system on which the machines have to operate, but a study of a particular case may help to bring out the advantages and disadvantages of the respective types.

When dealing with reactance control, a case was considered where two ranges of voltages were required, i.e. 400 to 440 volts for lighting and power, and 500 to 550 volts for traction. As these requirements are fairly common, they may serve as a basis for comparison.

Cost.—For this voltage variation, the booster would require a range of ± 75 volts, which means that its output would be 15·8 per cent of the converter output. This is on the assumption that the full range has to be obtained in a smooth curve, which is usually specified in such a case.

Assuming a unit of 1,000 kw. output, the cost of the booster would be in the neighbourhood of 20 per cent of the cost of the converter alone.

In the case of reactance control, the cost of the converter would be practically the same as for the booster control. Owing to the reactance and the tappings required in the transformer, the cost of this would be increased by approximately 5 per cent of the converter cost.

A three-pole double-throw switch would be required, the cost of which would be about 2 per cent of the converter cost.

From the point of view of first cost, therefore, the advantage would be with the reactance control. The size of the booster would of course be materially reduced by arranging the transformers with tappings giving 420 and 525 volts respectively on the continuous-current side and providing a change-over switch as in the case of the reactance control. The advantage of this arrangement would be not only reduced cost but also improved conditions from a point of view of commutation, on account of the reduced boost. This advantage is more marked in large units than in smaller ones, owing to the increasing difficulties in commutation.

Power factor.—As regards the power factor, the booster type of converter has, as already stated, the advantage, as its power factor can be varied at will under all conditions of load and voltage, and, in cases where wattless currents are required for power-factor improvement independent of the voltage conditions, it is the only type suitable.

When no leading currents are desired, however, there appears to be little or no reason why the reactance type should not be used, as the power factor obtainable on the high-tension side is very close to unity over the whole range of voltage, and is slightly leading at the higher voltage, and it is doubtful whether better results would be obtained with the booster type, as very close adjustment is necessary to keep the power factor exactly at unity, and it should be remembered that in order to maintain unity power factor it is necessary to adjust the field of the converter, as well as that of the booster, when changing the voltage of the converter.

With the reactance type of control, it is only necessary to operate the field rheostat in changing the voltage, and the fact that the power factor is fixed definitely for each voltage is therefore not altogether a disadvantage, as less skill is required in operating this type of machine. Another point which should be considered is, that if load having a power factor of approximately unity is added to a system having a low power factor, the conditions are of course improved in this respect, so that the converter acts as a power-factor improver without actually supplying leading current to the system.

Commutation.—In this respect the reactance control has the advantage, as good commutation is more easily obtained with this type. It is surely not necessary to state that satisfactory commutation can be obtained with the booster type of machine, as this has been demonstrated by the number of machines actually in operation; but much finer adjustments as regards interpoles, brush-gear, etc., are necessary with this type of machine than with the former type if these results are to be obtained. This is of course due to the change in the interpole strength when the booster is loaded, and it is clear that commutation is taking place under adverse conditions when the commutating field is of incorrect strength, hence the necessity of keeping all other conditions, upon which the commutation depends, as perfect as possible. There is no interference with the interpole strength due to the wattless currents, and the non-booster type operates therefore under more favourable conditions in this respect.

The object of the comparison is to bring out, if possible, the fact that in many cases sacrifice is made in the most vital feature of the machine, i.e. the commutation, in order to obtain the advantage of unity power factor, which may, or may not, be realized in actual operation.

SUMMARY.

The following summary of the two systems may be considered as generally applicable :—

	Reactance type	Booster type
Cost	Cheaper	—
Power factor ...	Cannot be controlled at will for each voltage and load	Can be controlled at will for any load and voltage
Commutation ...	Good commutation more readily obtained	—
Range of voltage...	Limited (± 7½ per cent may be considered as the limit)	Great range can be obtained (± 15 per cent or more)
Efficiency ...	Slightly higher	—
Starting	No difference	No difference
Space	Less space required	—
Maintenance ...	—	More parts to keep in order

From the foregoing it will be seen that the question of voltage regulation of rotary converters is one which requires close consideration from every point of view, in order to obtain the best results as regards first cost and operation.

The simplicity of the reactance control, coupled with its low cost and advantages in operation, are factors which recommend it very strongly wherever the range of voltages required permits its adoption, even at a sacrifice in way of power factor, and it may not be out of place to emphasize again the fact that although the power factor may be slightly lagging at the high-tension side of the transformer, the general power factor of the system may be improved.

APPENDIX I.

The following expression gives the total instantaneous alternating current at any point of the winding of a rotary converter :—

$$I = \frac{(1 \pm p)\, 4\, I_c \sin(\theta + \psi)}{(1 - b)\, m \sin(\pi/m) \cos\psi}$$

where I_c = continuous current.

θ = angle of displacement between the mid-point between two taps and the point of commutation.

ψ = angle of displacement between the current and the E.M.F. of the converter, due to wattless current in the converter.

m = number of phases in converter.

p = per cent boost.

b = no-load losses in converter in per cent.

[illegible] is the difference between the continuous and alternating currents, and is then

$$i = I\left[1 - \frac{\text{[illegible]}}{(1 - \text{[illegible]})\, m \sin(\text{[illegible]})\cos\varphi}\right]$$

Considering a coil at a point B on the winding displaced [illegible] the mean square value of the resultant current is

$$\text{[illegible]} = \int \text{[illegible]}\, I^2\left[1 - \frac{\text{[illegible]}}{\text{[illegible]}}\right]^2.$$

The ratio of the losses in a coil at the point B of a rotary converter, to the losses there would be if continuous current alone flowed in the winding, is therefore

$$\frac{H}{H_c} = 1 + \frac{\text{[illegible]}}{\text{[illegible]}}\left[\frac{8}{m^2 \sin^2(\pi/m)} + \frac{8\tan^2\varphi}{m^2 \sin^2(\pi/m)}\right]$$

$$- \frac{(1 \pm f)}{(1 - \eta)}\left[\frac{16\cos\theta}{\pi m \sin(\pi/m)} - \frac{16\sin\theta\tan\varphi}{\pi m \sin(\pi/m)}\right].$$

In the case of a six-phase converter, the ratio of the losses in the tap coils will be obtained by putting $m = 6$ and $\beta = 30°$. Inserting these values in the above equation and denoting the ratio by K_T, we obtain

$$K_T = 1 + \frac{(1 \pm f)^2}{(1 - \eta)^2}\,(\text{[illegible]} + \text{[illegible]}\tan^2\varphi)$$

$$- \frac{(1 \pm f)}{(1 - \eta)}\,(1{\cdot}47 - \text{[illegible]}\tan\varphi).$$

The ratio of the average losses over the whole winding of a converter to the losses if the winding carried continuous current only, is, as is well known, obtained by integrating the tap-coil losses K_T over the whole phase band.

In a six-phase machine the limits would then be ± $\pi/6$. Denoting the average losses by K_a, and considering the case of a six-phase machine, we obtain

$$K_a = 1 + \frac{(1 \pm f)^2}{(1 - \eta)^2}\,(\text{[illegible]} + \text{[illegible]}\tan^2\varphi) - \frac{(1 \pm f)}{(1 - \eta)}\,(\text{[illegible]})$$

APPENDIX [illegible]

([illegible])

In dealing with the different methods of voltage control, one of the earliest schemes adopted has not been mentioned, i.e. the booster-transformer type of control. As this method provides means of obtaining almost any range of voltage control, without in any way interfering with the commutating conditions of the converter, it is worth studying. The general feature of this method is that the voltage variation is obtained by varying the voltage impressed on the primary winding of the booster transformer. As the change has to be made in steps, the closeness of the regulation depends on the number of steps provided, and when a large range is required the number of connections necessary may be prohibitive.

It is possible, however, to obtain a very fine regulation with a small number of steps by the use of a small auxiliary regulating transformer, as shown diagrammatically in Figs. 11, 12, 13 and 14. For simplicity only one phase has been shown. In Fig. 11 the auxiliary regulating transformer is shown connected across the first tappings of the main transformer, and it is clear that the voltage across the primary can be increased in small steps until the voltage of the first section of the main transformer is obtained. The connections are then as shown in Fig. 12. It is then possible to disconnect one end of the auxiliary regulating transformer from the main transformer tapping (see Fig. 13) and connect it to the third tapping, as shown in Fig. 14. The boost can then be increased until the third tapping of the main transformer is reached and the electromotive force across the primary winding of the booster transformer is equal to that of the first two sections of the main transformer. The auxiliary regulating transformer is then switched over to the next tapping of the main transformer, and so on until full boost is obtained. By this means the total number of steps available is the product of the steps of the main and auxiliary transformers.

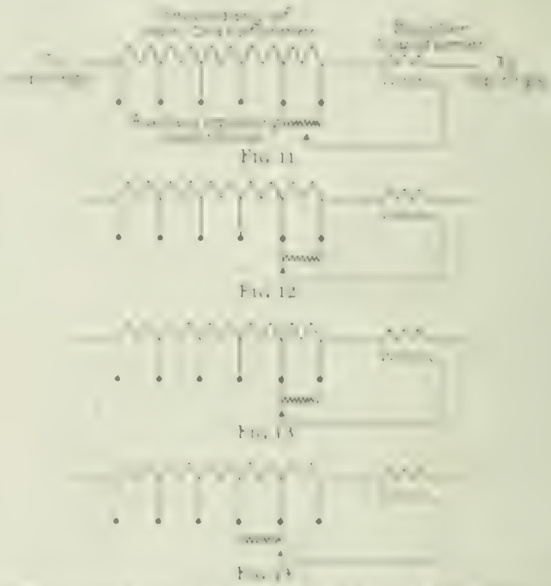


FIG. 11

FIG. 12

FIG. 13

FIG. 14

Diagrams showing arrangement of booster transformer and auxiliary regulating transformer.

For example, if each had five steps, we should have 25 steps up or down, giving 50 steps for the total range of voltage.

It should be noted that the capacity of the auxiliary regulating transformer is only a small fraction of that of the booster transformer, the size depending on the number of steps provided on the main transformer.

In connection with the regulator dials, or controller, it should be noted that no power is broken when changing the auxiliary transformer from one tapping to another, and that for this reason there will be no wear of the contacts used for this purpose.

The voltage per step of the dials for the auxiliary transformer is extremely small, and the wear of these contacts should therefore be negligible.

As regards cost, this arrangement would be cheaper than a booster dealing with the same range, and, considering the advantage gained by non-interference with the commutation, this method deserves consideration.

DISCUSSION BEFORE THE INSTITUTION, 8 MARCH, 1917.

Taylor

Mr. A. M. TAYLOR: This paper is very interesting; and the rotary converter is at present so largely used in substation work as to warrant the fullest consideration of its possibilities. I take it that the paper is intended to show that the reactance-controlled rotary converter is rather more useful, and at any rate cheaper, than the booster-controlled machine, but I somewhat disapprove of the use of the former for certain purposes. The purpose that I am more particularly interested in is its use in, for example, a substation at the distant end of a large power system, and with a large alternating-current load beyond it, where the voltage is, or may be, necessarily low and where possibly the power factor may also be very poor. It would doubtless be a great advantage if we were able to boost up the supply at a distant point like that. I have in the past been rather partial to the use of batteries—and incidentally I may say they have proved a great success—and I cannot help thinking that in many such cases batteries supplying inverted rotary converters would be very useful. If it were possible to feed into the alternating-current network from the substation battery and at the same time to boost up not only the voltage but also the power factor of the alternating supply, I believe that engineers would not hesitate to pay perhaps 15 to 20 per cent more than they do at present for rotary converters, in view of the considerable saving in copper which would be effected in the mains. I endeavoured to show, some years ago, that it was financially a safe proposition to install batteries in the more distant substations, even on the basis of unity power factor in the alternating-current load, on account of the saving in copper in the extra-high-tension mains; when the power factor was poor, much more would this be the case. I believe that it is possible to obtain a large leading current from the rotary converter, both when it is delivering continuous current to the substation busbars and also when it is running inverted off these busbars, i.e. over the whole 24 hours, and this desirable result can, I suggest, be obtained in either of two ways:

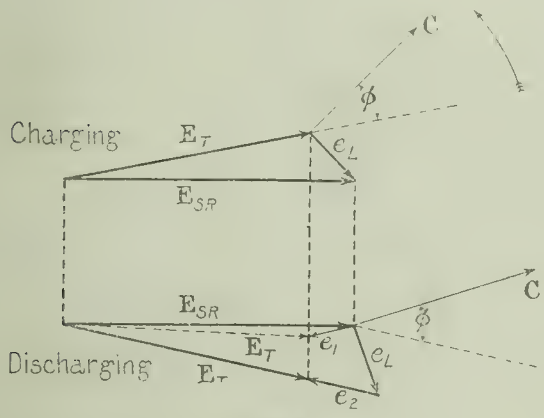


FIG. A.

E_T = voltage across high-tension mains
E_{SR} = " " slip rings.
e_1 = counter boost; no reactance, or reactance out.
e_2 = " " reactance in.
e_L = voltage across reactance.

Mr. Taylor.

(1) A rotary converter with a large external reactance can be used on the charge, and the converter designed to give the correct continuous and alternating voltages when heavily excited (i.e. with a large leading current), the reactance in this case acting to give a heavy positive boost from the a.c. mains to the c.c. mains. The same converter, with the reactance cut out by a switch and with the addition of an a.c. booster (or induction regulator) giving a large counter boost, can again be run at a high excitation and with a large leading current, this time inverted and feeding into the a.c. mains. The vectorial conditions are shown in Fig. A.

(2) The alternative would be to have only the a.c. booster (i.e. without the reactance) and to have the rotary converter and transformer with as little reactance in them as possible. In this case the converter would be run over-excited on the charge as well as on the discharge (i.e. when running inverted) and would take a big leading current in each case. The booster would be used to give a counter boost on the discharge only; or, if found more desirable, it might give a forward boost on the charge and a counter boost on the discharge. The vectorial conditions for the former case are shown in Fig. B.

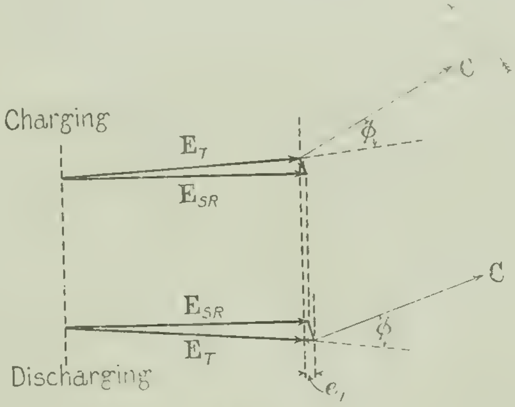


FIG. B.

Both vector diagrams are constructed on the assumption that, when running inverted, the rotary converter is always motoring: with combined continuous and (lagging) alternating current when the field is too weak, and with (leading) alternating current alone when the field is strong, as I recommend. I disagree entirely with the author that the machine ever generates when running inverted. It is of course unnecessary that the required boost be furnished by a rotating booster. It could be equally well provided, for instance, by the new type of static regulator described by the author at the meeting; this regulator also has the advantage that it could be added to any existing rotary converter.

Mr. Brazil.

Mr. H. BRAZIL: I gather that the author generally is in favour of the reactance-controlled rotary converter, and [illegible] which I have used for obtaining [illegible] manufacturers that continuous-current boosters should be [illegible] reactance-controlled converter for a three-wire system, I was told that the idea was impracticable, due to the fact that the a.c. input at the slip-rings would be considerably greater than the c.c output on the commutator, and this would cause severe sparking. I felt convinced, however, that a machine could be designed which, when giving 10 per cent of its output on the c.c. boosters, would run satisfactorily, and the results in actual practice have more than fulfilled my expectations. This arrangement has some advantage over the rotary converter with a.c. booster, as for the ordinary lighting supply the machine can be used with reactance control only, there being no [illegible] control is required, one or both of the boosters are put in circuit, and the machine can then be used for charging or discharging batteries, or raising the pressure on any particular feeder. The c.c. boosters are arranged so that they can be entirely disconnected from the c.c. supply of the rotary converter, and they are very useful for testing switches, fuses, instruments, etc., this not being possible with the a.c. booster. Coming now to actual results, we have a 500 kw. rotary converter with c.c. boosters at each end, from which we have taken 15 per cent of the output of the converter, and then increased the input on the a.c. side of the converter to 25 per cent above normal without any appreciable sparking, the brushes on the converter and the booster commutator being fixed in position. If the 15 per cent obtained from the boosters [illegible] be similar to the case of the rotary converter with a.c. booster, but as the machine would be run normally with only a 4 per cent variation obtained by reactance control, and the c.c. boosters would always be [illegible] designed to have a good power factor, and to give less [illegible]

Dr. [illegible] control. He points out [illegible] of regulation can be obtained [illegible] w whether, [illegible] required to obtain the higher voltage necessary on the line should give a leading power factor. It is necessary on practically all systems of supply to correct the power [illegible] arrangement I have described can be utilized with the reactance method of control instead of installing boosters. I quite agree that the booster type is a nice machine to run, but it costs more to install and is more complicated. Simplicity in all these arrangements is very desirable, and I think that on this account the reactance type of control should be utilized wherever possible. The difficulty of changing over from a lighting voltage to a traction voltage, i.e. from 450 volts to 550 volts, can be easily got over by some simple form of throw-over switch to alter the connections of the transformer tappings. From this point of view, therefore, there is no objection to the reactance type of control.

Mr. H. BURGE : I think this paper is of very real value, both to operating and designing engineers. There are a few questions I should like to ask with regard to it. In Fig. 10 a curve is shown of the copper losses in the converter. I should like to ask whether that applies to the six-phase machine or to the three-phase machine. Also I am not quite clear what the author means by the term "reactive iron" in transformers. I have supposed it to be some leakage path that is provided on the transformer. From what the author says, it appears undesirable to depart from the simple converter, which as it stands has such excellent commutating properties; therefore we should not attach boosters to it, whether they be at the alternating-current or continuous-current end. At any rate a continuous-current booster means adding another commutator equal in size to the rotary converter commutator. Perhaps it would be feasible to have a separately-driven booster running at a higher speed, and thus of a smaller size, driven by a synchronous motor. The booster would of course be connected in series with the converter slip-rings when required.

Dr. S. P. SMITH : When discussing the question of the relative advantages of reactance control and booster control with another designer some time ago, I asked him what determined which he put forward when it was left to his choice. He replied that the rule he had to follow, sometimes against his own wish, was to put forward the type that the other firm was not putting forward, and of course prove that his was the best. That I think has determined a good many cases where a booster-controlled converter is used. When discussing the real problems with this same designer, we both agreed that booster control had been rather overdone in the past, and it was not likely it would be used to such a wide extent in the future. There is no doubt that the difficulty of commutation prevents the designer from using the material of the booster to the best advantage, unless rather intricate methods of obtaining good commutation are introduced, [illegible] reactance control. The author refers a good deal to straight-line reactance. I believe I am right in saying that [illegible] but I cannot see at present how we can design a transformer to give straight-line reactance up to 300 per cent overload, unless it is a very abnormal design. I think such a transformer could not have any reactance iron in it at all. We might be able to do it with air, but I should not like to say what the losses would be in that case. In the other case of the transformer with saturated iron, I believe it will be found that saturation generally occurs much before full load; it may occur at half load or quarter load. With saturated iron, as the author mentions, the secondary voltage is no longer proportional to the current; therefore it is no longer a sine wave, like the supply pressure and the rotary converter E.M.F. The effect of applying to the slip-rings of the rotary converter the resultant of the sinusoidal supply pressure and the non-sinusoidal reactance pressure is to cause reactive currents to flow, which may prove disastrous to commutation, as many designers know. Thus it is not booster control alone that causes unbalanced magnetomotive forces inside the rotary converter, and when we make a comparison between booster control and reactance control, however one may dislike the former, it is only fair to emphasize the disadvantages of reactance control with saturated iron in the transformer. I should like to hear the author's opinion as to how far he would carry the comparison between the two methods of control when there are troubles due to saturated iron.

Mr. F. P. WHITAKER: The author has told us that the reactance-controlled machine is by far the best type to use in cases where the range in voltage is moderate, and in cases where the power factor can be varied over a reasonable amount. I think most designers agree with that standpoint, and a great many operating engineers as well. I have persistently advocated the reactance type of machine, especially where there is one range for lighting and another range for traction, as it really forms an excellent combination. But we all know there are cases where we require more than a moderate range of voltage, or where we want unity power factor or perhaps a leading power factor under all conditions of load and voltage. I am afraid that there the author has not left us very much choice. He has told us that we must either put up with a machine that has a limited booster range, or we must allow it to spark, or we have to introduce complicated commutating-pole adjustment devices, or complicated switching arrangements with auto-transformers. I do not believe the outlook is anything like as black as this. The booster machine is a perfectly satisfactory machine so long as it is liberally designed, but the booster does cause discrepancies in commutation; and, as we raise the rating of the machine, so these discrepancies in commutation become more and more important. With the introduction of commutating poles on rotary converters, and with a better understanding of wave-shape effects, and of reactance, instability of multipolar armatures, and the effects of self and mutual inductance, enormous improvements have been made in economizing material. Reactance-controlled machines, can now be built at speeds which are out of the question for booster machines, except when these latter are built with diverters or some special form of winding on the commutating poles to compensate for discrepancies due to the booster. We know that a great many machines are installed in America with special commutating adjustment windings fitted to the commutating poles to enable these machines to carry the full-load current over the specified voltage range. These windings are in some cases operated by contactors which cut them in or out as the load varies, but I do not believe that engineers in England would install such machines. The booster machine is perfectly satisfactory so long as it is liberally designed. If this is done, then we shall find that the induction-regulator type is a cheaper, more efficient, and better machine. In the past the induction-regulator controlled machine has not found favour in England for several reasons. First of all the regulator was a separate piece of apparatus; it required external connections; it had to be connected up; the connections were not well understood, and engineers said, "I have enough apparatus in the station already." Then very often it required a separate ventilating arrangement, especially if it was a large machine. Furthermore, the whole outfit was more costly, and generally on account of the lower figure the booster machine has been installed in England up to the present. There are, however, induction-regulator machines in use to-day in which the induction regulator is mounted on the converter base-plate. Such sets are self-contained; they have no external connections and the regulator does not in any way affect the commutation of the machine. We can operate the machine over a range of 30 per cent or more without having the slightest effect on commutation. Such sets will give unity or leading power factor under any condition of load and voltage, and are of reasonable cost and high efficiency. I am certain that, as time goes on, material will be more economically used, thereby bringing about the disuse of the booster-controlled rotary converter and an increase in the use of the induction-regulator type. At the present moment I am installing 12 induction-regulator controlled converters for operating 24 hours a day and seven days a week at full load, and these sets have to supply their full-load current over a range of over 30 per cent; and I do not believe that any other type would meet such conditions so economically and so efficiently. I should like to have the author's opinion on that point.

Mr. Whitaker.

Mr. W. B. WOODHOUSE: Some of us in past years had hoped that the reactance-regulated rotary converter would have been a useful machine for correcting power factor. The author confirms our experience that this is not so, and that if we want the converter not merely to regulate its voltage but to help to correct for power factor on the system, we must adopt booster control. On page 250 the author makes a comparison between the cost of booster control and of reactance control. I should like to have his estimate of the cost of the third arrangement he describes, that is to say, the booster with the small range of voltage and a change-over switch.

Mr. Woodhouse.

Mr. R. G. JAKEMAN (*communicated*): This paper will be of great interest to designers, and I am particularly attracted by the curves on page 250 showing the variation of armature copper-loss according to the amount of boost. These curves are very instructive and have not, I believe, appeared before. The first idea of designers would naturally be to make the positive and negative boosts equal, in order to obtain the smallest size of booster. These curves, however, show that a large positive boost increases the converter armature copper-losses and therefore may increase the size of the converter. Hence it is possible that by using a larger negative boost than

Mr. Jakeman.

[illegible] re wave, which will [illegible] bad sparking and a pulsating pressure on [illegible] places. On page 212 and elsewhere, the author speaks of [illegible] at the converter" being unity, but he [illegible] in that this figure is of interest only [illegible] that the actual power factor which the [illegible] r or consumer has to deal with has quite a different value. Then, again, the expression cos ϕ is almost universally used to mean the power factor of the load. The author, however, uses ϕ as the angle between two voltages, and the power factor which interests the supplier or the user is given by the complicated expres- [illegible] stand if the ordinates were [illegible] current. To say a machine is taking a wattless current of 30 per cent means as much to the average mind as to say that the angle of lag or lead is 18°. It conveys much more to [illegible] cing the saturation into the vector [illegible] l be still higher if the direction of [illegible] ndicated by an arrow-head.

Professor E. W. Marchant (*communicated*): The vector diagrams in the paper are extremely simple and provide an [illegible] tary converter. They do not, however, accurately represent the conditions when the reactance of the converter itself is the only one in the circuit. It is very difficult to [illegible] n. I presume that the vector diagrams are [illegible] e case in which the converter is only a small [illegible] total reactance in the circuit. In comparing [illegible] ls of voltage regulation for rotary converters [illegible] e paper, the author states that the efficiency [illegible] e type of control is slightly greater than it [illegible] the heating is over 30 per cent [illegible] for that reason it has not been much used. It would seem, however, to offer some advantages over the simple booster control as described by the author, since there is no generator or motor armature-reaction to complicate commutation, such as arises when the synchronous booster is used, and the power factor of the converter can be maintained at unity for all voltage fluctuations. When using an inverted rotary converter the question of speed control is of course the chief difficulty. I have in my laboratory a small rotary converter built by the British Westinghouse Company with a separate exciter having a very steep "volts-speed" characteristic, which has given excellent results. With a power factor of 0·1 on the alternating-current side the speed variation was less than 7 per cent between no load and 2·5 times the full kilovolt-amperes. This load cannot, of course, be taken for more than a short time, because of heating. This type of machine is useful for laboratory purposes, as it provides a simple means of obtaining alternating current varying in frequency between considerable limits, which may be controlled by a resistance in the field circuit of the converter, which, at the same time, is protected against the risk of overrunning when the load on it is varied.

Mr. G. A. Juhlin (*in reply*): I quite agree with Mr. Taylor's objections to the reactance-controlled machine when operating under conditions such as those suggested, and I endeavoured to make it clear that, when power-factor improvement is desired by supplying leading currents from the converter independent of the voltage and load, it is not possible to use this type of machine. Referring to the question of the possibility of obtaining leading currents from the converter both when converting from alternating to continuous current and from continuous to alternating current, it is of course possible to make the converter take more than its share of the wattless load in the same way as an ordinary alternator, but it should be borne in mind that the ability of converters to carry wattless currents is limited, and with very low power factor on the feeder it may not be possible to supply wattless current from the converter in proportion to the watt load it carries. With reference to the schemes suggested by Mr. Taylor when running rotary converters in conjunction with batteries, I believe the range required for charging is outside the limit for reactance control and that boosters would have to be used. When running the converters inverted, it would be necessary to use some kind of automatic regulator so as to prevent the overloading of the battery and converter due to voltage variation of the alternating-current supply. It is hardly possible to make any statement as to whether such an arrangement would be successful from an economical point of view, as each case would have to be considered on its merits. The cost of the booster type of converter is considerably higher than that of the simple converter, owing to the necessity of [illegible]

I do not quite understand Mr. Taylor's remark that the converter does not deliver any a.c. load current when running inverted but only leading wattless current. If the converter is not supplying a.c. power to the mains I cannot see how any saving in copper in the extra-high-tension mains can be made when the power factor is unity, as it would be necessary to relieve the feeder of load to obtain this result. When the power factor is poor, some saving

Mr. Juhlin.

can be made by improving the power factor and without supplying any load current. In such a case it cannot be said that the a.c. network is fed from the batteries. If it is only desired to supply wattless current to the a.c. mains this can be done without the use of batteries.

The arrangement described by Mr. Brazil is very interesting. As far as interference with commutation of the converter fitted with a continuous-current booster is concerned, there is no difference whether the booster is of the continuous or alternating-current type, as mechanical power is transmitted through the shaft in both types and to the same extent if the amount of boost is the same. The results obtained in operation indicate that the machine in question is of a liberal design and that a cheaper machine could be produced if the voltage regulation were obtained by some other means than boosters mounted on the shaft. Mr. Brazil is correct in the assumption that the power factor can be controlled when a continuous-current booster is used as well as when an alternating-current booster is employed. The disadvantage of the continuous-current booster is considerable, as the commutator has to carry the full current, which means additional attention and maintenance; the cost is also higher than that of the a.c. booster.

In reply to Mr. Chattock, it is possible to obtain a leading power factor if tappings are provided on the transformer, but not to regulate the power factor independently of the voltage unless the tappings on the transformer are changed, and for the range between the different tappings the power factor is fixed by the design of the transformer.

In answer to Mr. Burge, I would say that the curves shown in Fig. 10 refer to six-phase machines. The reactive iron is introduced into the transformers to form a path for the leakage flux. The separately-driven synchronous booster has been considered but has not come into use, owing to the possibility of swinging being set up, which might prove objectionable.

Dr. Smith appears to have misunderstood Fig. 5, as it refers to per cent load and not per cent overload. There is no difficulty in obtaining a straight-line reactance up to this load, as the point of the load at which the reactive iron becomes saturated can be fixed by the design of the transformer. The influence of the saturated reactive iron is somewhat difficult to predict, and it is hardly possible to make a comparison at the present time.

I do not think Mr. Whitaker is justified in his statement as to the choice left by the paper when a large range of voltage is required or when leading currents are desired from the converter under all conditions of load and voltage. On page 241 several schemes for obtaining voltage variation are mentioned, and I described a further method of voltage control by means of a booster transformer (see Appendix 2). I do not think it follows that because a comparison is made between two methods, these are the only ones we can employ. The point I wished to lay stress on is that the reactance-controlled type has not received the consideration it merits, and that by carefully studying the requirements it is possible to employ this method with success for a greater range of voltage variation than is usually considered satisfactory. I agree with Mr. Whitaker that the induction regulator deserves consideration as a means of obtaining voltage regulation, but it is an expensive piece of apparatus, and I believe the booster transformer shown in Fig. 11 of Appendix 2 will be cheaper and more efficient.

I hardly agree with Mr. Woodhouse's conclusion that the reactance-controlled converter is not useful for improving the power factor, as it is possible to obtain a power factor of approximately unity with fairly large range of voltage, and if load of this nature is added to a system having a low power factor it does improve the general power factor of the system. It is difficult to give an exact estimate of the arrangement with a small booster and a change-over switch, as it may be possible to run the converter at a higher speed with the smaller amount of boost. Assuming that the same converter is used, the cost would be reduced by 6 to 7 per cent as compared with the large booster.

With regard to Mr. Jakeman's communication, I think it is clearly stated on page 247 that the power factor on the high-tension side differs from that of the converter, and the power factors at both points are given in the various tables. It is doubtful whether the curves in Fig. 7 would be easier to understand if the ordinates were expressed in terms of power factor. I believe the power factor at low loads would give a false impression as to the effect it would have on the system, and that this influence is more readily appreciated if the wattless current is expressed as a percentage of the full-load current.

The point raised by Professor Marchant, in connection with the vector diagrams when the only reactance in circuit is that of the converter itself, is very interesting. In most cases where reactance control is used, the converter reactance is a small part of the total, and no account has been taken of the irregular variations of the current in the armature. It is somewhat difficult to give any accurate figures for the efficiency of the two types. Higher speeds can be adopted for machines with reactance control, and the efficiency may therefore be from ½ to 1 per cent better for this type than for the booster type.

MANCHESTER LOCAL SECTION, 13 MARCH, 1917.

Mr. Townend.

Mr. R. TOWNEND: The rotor converter is primarily a machine for converting from alternating current to continuous current with as small a voltage variation as possible, and any increase in the voltage range is accompanied by some sacrifice in the heating, efficiency, power factor, or cost of the equipment. If the required voltage range is within the limits permissible with reactance control, this sacrifice may be small; but when the voltage range is outside this limit, some additional apparatus is necessary and then the sacrifice may be considerable. It is therefore important that the rotary converter should be designed for the voltage range under which it will have to operate, and this range should not be considerably increased in order to be safe. There is one part of the subject which the author has not dealt with, namely, the voltage regulation when the converter is running inverted (i.e. converting from continuous to alternating current). In this case the conditions are quite different from those when the converter is running alone and when it has alternating-current generating plant running in

Mr. Townend. [illegible] its voltage; therefore some form of auxiliary apparatus is essential if it is necessary to have control over the alternating voltage. If the rotary converter is running in parallel with alternating-current generating plant, a variation in its excitation cannot change the speed, because the converter must run in synchronism with the other machines, and therefore the change in field current causes a change in the wattless current flowing in the converter, this change being sufficient practically to neutralize the alteration to the field excitation. This change in the wattless current will of course cause a variation in the alternating voltage, provided there is some reactance in the circuit, exactly as in the case of a rotary converter converting from alternating current to continuous current and having reactance control. This variation in the wattless current of the converter simply means that the wattless current carried by the machine is now carried by the alternating-current generators (or vice versa), and it is therefore necessary to take care that this will not result in overloading these generators with wattless current.

Mr. Ellis. Mr. A. G. ELLIS: In deciding which system is the most suitable for any particular case, the question of reliability in service should be given careful consideration. In this connection the primary voltage of the system should be taken account of. In high-voltage transformers the introduction of magnetic shunts between the primary and secondary windings, in order to increase the reactance, is liable to weaken the transformer from an insulation point of view. Also for low transformer secondary voltage, i.e. low voltage on the continuous-current side of the rotary converter, large sections of copper will be necessary, which will be more susceptible to parasitic [illegible] A reactance up to 10 per cent can generally be obtained as inherent reactance of the transformer without resorting to the use of magnetic shunts of sheet iron placed between the primary and secondary windings, and while still retaining a rational design as regards material and efficiency. Above this value, magnetic shunts are usually necessary, and a reactance up to 50 per cent can be obtained by skilful designing with a short-circuit characteristic not deviating appreciably from a straight line. Such high reactance is, as shown in the paper (page 243), not usually necessary for the range of voltage variation required in practice. This is fortunate, as the disabilities as regards parasitic losses, space required for the reactive iron and mechanical solidity of construction, increase with the reactance. Even with very high reactance these difficulties are not, however, [illegible] arrangement is to provide a tap for the lower voltage on the low-[illegible] high reactance transformers to such an extent as is usual in England, but have often supplied the necessary reactance in the form of a separate choke coil in series with the transformer. This is partly due to the primary voltage often being very high on the Continental systems, and the consequent desire to avoid the introduction of reactive iron, for the reasons I have noted above. Booster transformers, apart from the question of cost, are undesirable on account of the extra complication and sources of possible breakdown introduced, namely, two extra transformers and a voltage regulator. For large rotary converters with wide voltage-variation limits, a large number of steps on the regulator will be required or trouble will be experienced on account of the large number of volt-amperes between contacts. This will lead to a large and expensive regulator, and such a fine degree of regulation is not usually required, especially in traction work. The series booster transformers also require special care in construction, as they have to stand heavy shocks in case of short-circuit.

Mr. Lindley Thompson. Mr. J. LINDLEY THOMPSON: There are one or two points with regard to the static apparatus mentioned in the paper about which I should like to make a few remarks. These points are: (1) Transformer with internal reactance; (2) transformer with external reactance; (3) static boosters and regulators. The adoption of any one method of those outlined for voltage regulation depends in my opinion on the following essential facts: (*a*) efficiency of complete unit; (*b*) cost of complete unit; (*c*) floor space required. For machines transforming power from alternating current to continuous current any of the three types of static apparatus can be used; for inverted running, however, alternatives (2) and (3) only can be adopted. Alternative (1) cannot be used on account of the excessive voltage drop, unless the machine is feeding an alternating-current system, as outlined by Mr. Townend. As regards the efficiency of the static apparatus, I find from investigation that whichever scheme is adopted the overall efficiency of the static apparatus is about the same, though the advantage, if any, is slightly in favour of that embodying the transformer having a high internal reactance. With regard to cost, the following figures will serve as a guide. The costs are given as a percentage of the cost of a transformer having normal reactance, this cost being represented as 100 per cent. For example we will take a 550-k.v.a., 3/6-phase, 50-period transformer with standard adjusting tappings such as would be used for a 500-kw. rotary converter.

(1) Main transformer ... ... [illegible]
(2) [illegible] former, extra cost of ... ... [illegible]
(3) 25 % reactance embodied in an ex[illegible] ... ... [illegible]
(4) [illegible] reactance ... ... [illegible]
Additional switchgear involved, extra [illegible] ... ... [illegible] } [illegible]

From these rough estimates it will be seen that the high reactance transformer is by far the most favourable as indley pson. regards cost, and as regards efficiency it also is equal to any other scheme. Floor space is very important; for from my experience of generating stations and substations, floor space is very limited and, in general, static apparatus is unfairly treated in this respect. From this point of view the high-reactance transformer is by far the most economical, while the external reactance is better than the static booster and regulator. If inverted running is required, an external reactance which can be short-circuited and adjusting taps on the transformer are necessary, or the alternative of the static booster. This condition is the most favourable for the static booster, and is the only case in which I should recommend its use. With a static booster it is necessary to consider its electrical position with reference to the transformer. If converting alternating current to continuous current, the low-tension side is the correct place, if converting from continuous to alternating current then it should be on the high-tension side, i.e. whichever conversion is used it should be on the secondary side of the main transformer in order to obtain the highest efficiency. If the rotary converter is feeding a three-wire continuous-current circuit, and the booster is on the low-tension side, then a six-phase booster must be employed, thus boosting equally each side of the six-phase neutral in order to obtain equal continuous-current voltages from the middle wire to the outers. This necessity of course involves further expense and depreciates the value of this scheme still further as regards cost. On page 243 the author refers to the reluctance of transformer builders to include more than 30 per cent reactance in transformers. While I agree with him on this point to a certain extent, I should like to say that higher values are not impossible. If higher reactance would assist rotary converter designers in any way they can have it, but at an extra cost, though that cost would not be excessive and would compare favourably with external reactance having the same value; the efficiency also would compare favourably. I have designed transformers embodying 45 per cent reactance, and these transformers are in commission and working satisfactorily. The high reactance of course increases the stray losses, but with scientific design these can be reduced to a minimum. With regard to the author's reference to cost, I should like to know if the comparative cost is on the converter alone, or on the converter plus the transformer.

Peck. Mr. J. S. Peck: One of the handicaps of the rotary converter is that the ratio between the alternating and the continuous voltage is fixed within very close limits, so that if it is desired to vary the continuous voltage it is necessary to vary the voltage impressed upon the slip-rings. There are several methods of doing this, and from the very first the reactance-control method has been extensively adopted, but when it was desired to obtain a greater voltage range than it was possible to get with the reactance control, or where power factor control as well as voltage control was required, it was customary to use a method similar to that outlined by the author on the board, i.e. some form of step-by-step control. In fact we went so far as to standardize the particular method of control shown in Fig. C, which will be self-explanatory. This system of control was used on rotary converters up to perhaps 500 or 600 kw., and was perfectly satisfactory in every respect except that the regulator dial itself gave Mr. Peck. trouble, and on account of these difficulties, which were largely of a mechanical nature, this type of regulator was finally abandoned in favour of the induction type which is even now being used to a certain extent, and which perhaps may again come into general use. It is also possible that the step-by-step regulator may again become popular, as it is the cheapest type which is available, and improved mechanical construction may make it entirely satisfactory. After the induction regulator came the synchronous booster, and we have to thank Professor Walker for its introduction on a commercial scale. This type of control came into very rapid use, first in this country, then in America, and then on the Continent, and rapidly superseded all other types. When the synchronous booster was first introduced, commutating poles were not generally used in connection with rotary converters, and the difficulties which have since been encountered in connection with booster control have been largely due to the use of the commutating pole, as explained by the author. As the commutating pole was more extensively introduced, the difficulty of obtaining proper commutation when a booster was used became more clearly recognized, and designers now hesitate to employ the booster except where special conditions make its use essential, but devices have been worked out which neutralize the effect of the booster upon commutation. These devices, however, introduce complications which it is desirable to avoid whenever possible; but where the booster is essential it is always possible to make it operate satisfactorily. Careful study will show that reactance control will give perfectly satisfactory service in many places where previously it was thought that booster control was necessary. The author has dealt with the general subject of reactance control in a most comprehensive manner, and has stated

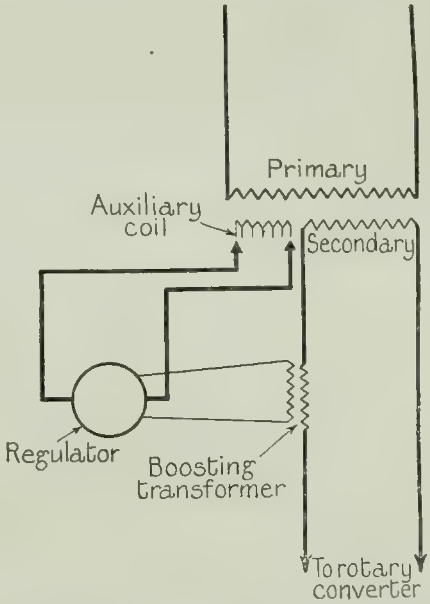


Fig. C.—Arrangement for varying the voltage on rotary converter by means of boosting transformer and tappings from auxiliary coil in main transformer (only one phase shown).

Mr. [illegible] more clearly the possibilities and the limitations of the system. I should like, however, to emphasize one point, viz. that with reactance control the power factor of the rotary converter improves with increase of the continuous voltage, which in general means that as the load increases, the effect of the converter is to improve more and more the power factor of the system.

Professor Walker. Professor MILES WALKER: A great deal could be said in praise of this paper, but as in the past we in this Institution have been prone to develop too much into a mutual admiration society, I think it may be well to attempt in this instance a severe criticism of the paper. The opportunity is a suitable one for this line of action, because the author and I are such good friends that he will not object to what I say; on the other hand, the paper is so thoroughly sound that it is difficult to find important points to criticize. However, I will do my best. In the first place, those of us who know the author will agree with me that we all expected a very much better paper; because while the matter is excellent, the manner of presentation leaves much to be desired. There is a looseness in the employment of terms which, however justified in ordinary shop conversation, ought not to appear in an important paper read before the Institution. For instance, the word "reactance" is continually used where the author means "reactance drop," and the word "resistance" is sometimes used to mean "resistance drop." Sufficient care has not been taken to make the clock diagrams clear. Every clock diagram ought to be accompanied by a small sketch of the connections to which it refers, showing the direction in the circuit taken as positive by the vectors in the clock diagram. Moreover, where there are various voltages dealt with in the problem, which vary their phase difference under changing conditions, the author should definitely state which of the vectors he takes as his standard of phase; otherwise it is very difficult for anyone studying the diagrams to get a correct notion of their exact meaning. A non-compliance with these simple precautions makes all the clock diagrams in the paper exceedingly difficult to interpret. Moreover, in Fig. 1 the scale of the vectors is changed without any indication of the fact to the student. The vector E_R is drawn of the same length in (A), (B), and (C), whereas E_T is made of different lengths, though we know that under practical conditions E_T is constant and E_R is variable. In the second paragraph on page 243 the author gives the merest indication of how the end of E_T moves on the circle, and he does not describe the method of applying the construction to Figs. 3, 4, and 6. This is greatly to be regretted, because we wish to encourage the third-year electrical engineering students to make a study of Institution papers; and unless the authors of the papers take special care to explain their constructions in a manner which can be understood by any good third-year student, the effect of reading the paper [illegible] not only to those students but to the Institution as well. The description in Fig. 7 is altogether inadequate, and I was in fact entirely misled as to what is referred to. The legend reads: "Curves showing wattless current in shunt-wound rotary converter." It then gives the percentage load as abscissae and the percentage wattless current as ordinates. The student naturally says: "I did not know that the wattless current in a shunt-wound rotary converter varied with the load to such a great extent as this." If the author had given in a short paragraph an indication of how Fig. 7 was derived from Fig. 6, and if the legend had read: "Curves showing the wattless current required to increase or decrease the voltage by $7\frac{1}{2}$ per cent on a rotary converter," the diagram would be perfectly clear. As a matter of fact, the curves are equally applicable to a rotary converter whether shunt-wound or series-wound, if the reactance drop in the transformer is the same. The reduction of the wattless current required to produce a given voltage variation when saturated reactance iron is used is of great interest, but it should be pointed out more emphatically that this gain is only possible where the reactance drop is used in reducing the voltage when drawing a lagging current. Attention should also be drawn to the fact that where the compounding characteristic is of the kind shown in Fig. 4 there is some danger, when a machine is being taken off load, of a sudden slump of load occurring as the load is being reduced, and a heavy reverse current being taken by the converter before the circuit breaker comes out on reverse current. As an illustration of the improvement which the author might have made in his paper with very little trouble, I may refer to the expression for tan ψ_1, on page 247, which the author makes equal to $(I_w \pm I_m)/I_a$. The ± sign in this case is very unsatisfactory. It would be much better to define the sign of the wattless current as, let us say, positive for the lagging current and negative for the leading current. The expression then becomes $(I_w + I_m)/I_a$, and not only do we avoid the ± sign, but the expression gives at the same time the correct sign of the angle ψ_1; so that a little lower down on the page it would not have been necessary to give two expressions for the power factor on the high-tension side, because $\cos(\phi + \psi_1)$ would be correct, and the sign of the resulting angle would itself indicate whether the current was leading or lagging. All the points that I have raised are minor ones, and do not affect the thoroughly sound and useful information given in the paper. I hope that in the future we shall not let off lightly authors of good papers who do not make every effort to present the matter in the most readable form.

Dr. Cramp. Dr. W. CRAMP (*communicated*): At a time when linking up is being so much discussed, a paper on this subject is of considerable importance, but it must always be remembered that these converters are not used only in connection with substation distribution for large districts, but that they are also installed to supply individual factories. This point of view seems to have been lost sight of in the paper altogether. The author speaks of wattless current to the extent of 50 to 60 per cent of the load current, and he omits to take into consideration the very serious effects of such a condition upon the consumer's account. He should remember that in many large towns electricity is charged for upon a kilovolt-ampere basis, and in consequence the purchaser has to pay for every ampere of wattless current whether this is lagging or leading. In such a case the control of power factor is of prime importance and it often pays to expend rather more capital to get control of the power factor than to use a converter with reactance control. Another point which is omitted altogether from the paper is the loss in the leads between the transformer and the converter. In the case, for

Cramp. instance, of a converter for 500 kw. and 250 volts (continuous current), the distance between the transformer and the converter might easily be so great as to lose ½ per cent or even more in efficiency at full load on unity power factor, and this will be considerably increased by the extra wattless current, which the author admits may be as much as 60 per cent of the load current. For these reasons the table on page 251 is really only a true summary for substation conditions. For private plants in general it is more economical and satisfactory to adopt either a booster control or a motor converter. With reference to the comparison between the rotary converter and the motor converter, the following figures, which are taken from estimates submitted a short time ago for 500-kw. 460-volt sets, will be of interest. The machines were required to operate at voltages varying from 440 to 480 on the continuous side. Under these conditions the figures were as follows :—

Rotary Converter.

420 Volts.

Load	¼	½	¾	1	
Cos φ ...	0·55	0·80	0·90	0·95	Lagging

480 Volts.

Load	¼	½	¾	1	
Cos φ ...	0·55	0·80	0·90	0·95	Leading

As against the above, the motor converter power factor only varied from 0·93 to unity over the same range of voltage and load. Dr. Cramp. Such figures speak for themselves and form a sharp contrast to the statement made by the author. On page 243 the author refers to the expression for the electromotive force of the transformer. It would be useful if he would give this in algebraic form. On page 248 the word "compounding" is used where it seems to me that the author means "over-compounding." Throughout the paper there is some confusion as to what is meant by lagging or leading current, i.e. as to whether the lag or lead is with reference to the generator or converter electromotive force. With regard to the comparative efficiency of rotary converters with reactance and transformers as compared with motor converters, I have generally found that in the makers' estimates there is about 1 per cent difference at full load, but, as already pointed out, this may easily be absorbed in the connections to the rotary converter, especially when heavy wattless currents are being used for reactance control. I notice that the author does not refer to the possibility of making use of a continuous-current booster instead of the alternating-current type. The machine may be rather more expensive, but it has the merit of leaving the power-factor control untouched and of not interfering with the commutation of the converter itself.

(Mr. Juhlin's reply to the discussion will be published in a later issue.)

YORKSHIRE LOCAL SECTION, 21 MARCH, 1917.

Selvey. Mr. W. M. SELVEY : The paper discusses voltage regulation of rotary converters rather than rotary converters per se. The troubles which I have experienced with these machines were not due to any question of voltage regulation, but to the design of the interpoles and their spacing. This is an important matter in large converters with heavy currents and quickly varying loads, and the author has probably this in his mind when discussing the variation of flux in the interpoles. In reviewing the whole subject, it is remarkable how much thought has been expended in remedying our former mistakes. One machine should not be expected to supply both traction and lighting, and to do either equally well with no appreciable increase in cost above that of a machine designed for a single purpose. I wonder whether we shall ever have simple straightforward apparatus designed for each particular purpose. Only under such conditions shall we arrive at the ideal of simplicity and cheapness without sacrificing other essential qualities.

Shaw. Mr. J. H. SHAW : Many rotary converters have undoubtedly been installed in this country with much larger voltage ranges than are necessary. I think the author should have definitely stated in the paper that rotary converters are unsuitable for excessive voltage ranges unless transformer taps are used. The Continental makers seemed to be well aware of this a number of years ago, when I had occasion to report on some tenders for 1,500-kw. rotary converters where a 20 per cent range in voltage was called for, 10 per cent up and down. I found that a well-known German firm had included for one or two small motor-generators to be connected somehow to the commutating poles of the converter ; in fact, the machines had an excessive amount of auxiliary gear. Mr. Shaw. I believe I am correct in stating that a rotary converter can be designed for a large voltage range provided that the regulation is effected by means of a shunt winding only. The commutating poles can then be excited in series with the booster excitation, and the armature distortion caused by the booster acting as a motor or generator can be neutralized. A further argument that might be used against the employment of booster converters on traction supply is that any attempt at power-factor correction is impossible on account of the rapidly changing load. I am of the opinion that the author has made too much of the advantage of being able to obtain leading power factor at full load and overload. If the case of a suburban railway system be considered with perhaps only a few trains per hour, it is quite possible that one substation might be fully loaded when the substations on each side are lightly loaded. It is, however, some advantage that the heavily loaded converter should work with a leading current as, of course, the lightly loaded machines will be running with a lagging power factor, thus tending to maintain unity power factor on the system.

Mr. Brown. Mr. W. H. BROWN : The author apparently emphasizes the advantages of reactance control as against the booster method, and where the voltage variation required is comparatively small there appears to be no question as to its being the better method. I wish he would let us know to what extent the voltage ratio may be altered by varying the design of the poles ; that is, how far the usual ratios of 0·70 and 0·61 for single-phase and three-phase rotary converters respectively may be varied by merely altering the shape of the main poles. In the case I have in mind, the converters [illegible] is a value which a customer might properly ask for when inviting tenders, or whether the matter should be left to the discretion of the builder. I should also like to ask in [illegible] whether a change of tap could safely be made whilst the rotary converter was on load. To me it appears that under these conditions [illegible] be of very small value if continuity of running were desired.

(Mr. Juhlin's reply to the discussion will be published in [illegible]

Mr. B

HONG-KONG LOCAL CENTRE : CHAIRMAN'S ADDRESS.

By F. Graham, Member.

[illegible] 3 November, [illegible]

In opening this address I would remind you of the substance of your immediate Past Chairman's address delivered [illegible] observations upon the same.

Mr. Carter reviewed the relations subsisting universally between the public and the public service corporations, or, as termed in the United States of America, public utilities. He argued that there was a school of thought in every country that favoured the acquisition of public utilities by the State, and curiously enough this school had disciples in China. He then gave figures regarding public services in Europe and America, and showed that the acquisition by a State or Province of its utilities did not always lead to increased efficiency. He also compared [illegible]

[illegible] in the world on public utilities, and the judicious manner in which these services are managed, are indicative of the degree of civilization and culture of that country.

When we turn to the public utilities of China, we find the facilities of transport, water and lighting supply, sewage disposal, telephone and telegraphs, practically non-existent, and this in spite of the enormous natural and intrinsic resources possessed by our neighbour ; and we come to the conclusion that only a mere fraction of this wealth has been expended to ameliorate the conditions [illegible] why the Chinese do not emulate the foreigner more in this [illegible] its benefits. The reasons are many. [illegible]

[illegible] have been started under apparently favourable auspices, [illegible] the extraordinary system of Chinese finance ; for while the Chinese are the finest shopkeepers in the world, they are also the worst business managers. I am under the impression, for instance, that before capital can be raised in China proper for an industrial or utility scheme, the promoters must guarantee a fixed dividend varying from 8 to 12 per cent per annum ; and so insistent are the shareholders on receiving their dividends, that unless the concern earns a good margin over the dividend payment it will eventually become bankrupt, or, if it escapes that fate, it has rarely a sinking or reserve fund for extension of plant or for emergencies. We are therefore faced by the fact that practically all the industrial concerns in China that have proved successful hitherto are managed by foreigners acting as sentinels for foreign money invested. This custom of the Chinese of expecting a guaranteed dividend before capital can be raised is a heavy handicap against small lighting stations, as a company in which I am interested would not exist to-day had it tried to follow this custom ; in fact it was six years before the company was able to make any provision for depreciation, much less pay a dividend, but the following year it was able for the first time to pay its directors their fees, and a dividend of 5 per cent as well as to make provision for depreciation. Since then the company has made steady progress, but had it attempted to pay dividends from the start it would have been bankrupt in a very few years. In fact the progress of the company after its first struggle for existence may well be used as an example of European finance as compared with Chinese.

Recently we met in Hong-Kong to discuss the important question of the "Standardization of Electricity Supply in China." The discussion brought out some interesting views and opinions, and while most of us here realize how important this question is for posterity, I doubt whether there are many of us who have realized the difficulties before us. The question of the standardization of any commodity or monetary unit will always present difficulties in China that exist in no other country in the world, as on the one hand we have the great size of the country compared with its mileage of communications, [illegible]

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* [illegible]

of the country, and on the other hand the extraordinary conservative nature of its people, its interclan differences, and its interprovincial jealousies, these I submit must always tend to prevent standardization, the most important factor of which is combination and agreement. Thus we sometimes feel that China with its 7,000 dialects, each dialect representing a different interest or disruptive factor, will never standardize even the dollar; but we as engineers can make a resolve that whatever plant we are asked to specify or supply shall conform to the standard our parent institution has set up. With regard to electrical plant and apparatus, however, we find all countries of the world competing for Chinese custom and trade, and I submit that any plant from these countries will be manufactured according to the nationality of the vendors. It is quite impossible to think that we shall ever work with the Germans in China for the standardization of anything except the sanctity of international law.

I am informed by those who have been upon the upper reaches of the Yangtse River that they have been thrilled to think of the power going to waste in this mighty stream, and we are inclined to ask whether as far as a comprehensive scheme of power supply and distribution it will ever be utilized. We know that a great many installations and lighting stations are being installed in China, and the same mistakes being made that were made in England, isolated plants with a high maintenance and first-cost factor being installed where many could be embraced by power schemes on a moderate scale. With regard to those plants already installed and native owned, we can never hope to bring them into line in the way of adopting a common standard, as, even should they wish to do so, I have already shown that few companies have any reserve fund at all to make the necessary alterations, and after all it is very difficult to convince the Chinese as to the advisability from an economical point of view of changing their voltage and periodicity.

There is one thing that we are all beginning to realize, and that is, as pointed out by Professor Smith in his paper some time ago on the electricity stations of China,* the great love of plenty of light, and preferably electric light, that the Chinese have. We find that China late in her life has suddenly awakened and demanded the luxury of modern artificial lighting, and seems to have plumped for electric light rather than gas light, so that electrical engineers entering China for ground to conquer find that they have at least no gas companies to compete with. This, of course, is not true of Hong-Kong. I am informed by my colleague in Canton that the demand for light since the revolution has been phenomenal, and in view of the scarcity of skilled labour in his district, and the natural reluctance of his Chinese directors to order reserve plant in advance, he is quite unable to cope with the demand.

Being a station engineer, I naturally take a keen interest in supply prospects and problems in the Far East, and one has a certain amount of pride in pointing to the Shanghai electrical undertaking. According to the yearly report for 1915 of Mr. Aldridge, the chief engineer, we find that the load factor at Shanghai was 40·8 per cent, while of the five largest British municipal electricity supply undertakings, in 1914 Manchester, the largest, had the best load factor, which was only 26·98 per cent. Here we have a concrete instance of an electric light and power scheme of some magnitude which has been built up in China under a foreign regime and which during the past few years has advanced by leaps and bounds. Shanghai has now over 18,000 house connections, approximately 14,500 horse-power of motors connected to the mains, and 2,400 kw. of heating and cooking apparatus, which last makes us envious in South China. Still, though our winter is short, there is a small and increasing demand for heating and drying purposes, and we hope later on in Hong-Kong, when we get the plant to supply it, to develop a large cooking load. It is the large demand for power which gives Shanghai its magnificent load factor, and as its climate and local conditions are more suitable for mills and factories, in South China we can hardly hope ever to rival them, but we may follow humbly in their footsteps, and we in Hong-Kong have already to thank them for great assistance in doing so.

In Hong-Kong last year the load factor was 29·06 per cent. In Canton we find a station and distribution scheme that is Chinese owned having a plant capacity of 2,600 kw. with an additional 1,400 kw. on order, and possessing a load factor of 26 per cent. The problem of distribution in Canton is a very interesting one, as indeed it is in any large Chinese city, as the streets are narrow, tortuous, and over-roofed, and are really drains full of black sludge covered over with granite slabs, making distribution by underground cables impossible, so necessarily the overhead system with pole transformers is adopted. Four-fifths of the city being below river-level, underground substations present great difficulties, as on the spring-tides the low-lying portions of the city are flooded. The present demand for power is, I am told, small, as the cost of manual labour is low, and Canton at the present time resembles somewhat the condition of our large manufacturing centres at home a hundred years ago, inasmuch as the majority of Canton manufactures are produced by individual artisans rather than by the centralized factory; indeed this is the present state of affairs in the average city and town in China, and out of which the Japanese with their city Osaka have just emerged. In Canton I note that the British engineers in charge of the electric power plant have for some time advised their directors to build a new turbine station on modern lines and on a comprehensive scale.

The Hong-Kong Electric Company's new generating station at North Point will contain two 1,500-kw. turbo-alternators, generating current at 6,600 volts, three-phase 50 periods; following Shanghai again, it has adopted the British standard of 50 periods, but it is unfortunate that the supply at Kowloon and Canton should be at 60 periods. The periodicity at present in Hong-Kong is 75 periods, but I think the decision to change it was a wise one, as the company and its consumers both gain by the change. Four of the existing Diesel engine-driven alternators at Wanchai will be rewound for three-phase 50 periods and run in parallel with the turbo-alternators as required.

Two three-core 6,600-volt feeders will connect North Point with Wanchai, and a new static substation in Sutherland-street will be supplied by one feeder from North Point and one from Wanchai.

With regard to the telegraphs in China, you are aware that these are controlled by the Government, and here

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* *Journal I.E.E.*, 1916, vol. 54, p. 162.

[illegible] that although the Chinese are quick to grasp [illegible] they [illegible] We all hope to see [illegible] — [illegible] er with the mines and railways, one day [illegible] rd of foreign and Chinese engineers.

[illegible] I might say that we are apt in these days of commercial electricity supply to neglect the finer technical field of telegraphy; certainly the two branches possess almost equal importance, for although we could do without electric light for a time, the [illegible] imagined. Let us remember that our parent institution was formerly a society of telegraph engineers, formed to promote the general advancement of electrical and tele[illegible] As we all realize, the Chinese evince a great desire to keep the control of industrial schemes in their own hands, and when the present unrest in China is over and the country settles down to an era of progress, she will certainly endeavour to use her foreign-trained children, and the British Government must be brought to see that Chinese who have orders to place have a distinct leaning towards the country in which they have been trained. I think we all agree that it is better to train a Chinaman in his own country [illegible] The Hong-Kong University fills a long-felt want in South China, and the great need for British-endowed universities and schools in the Far East has yet to be fully realized at home. As we hope [illegible] goods, we shall find that Germany will exploit China to [illegible] some of us are beginning to realize that our public schools at home would be rendering the com[illegible] teaching Chinese and Russian instead of the dead languages.

The War has taught us many lessons that we are grateful to learn in the Far East. Our pre-War supplies came with unfailing regularity, until we became more or less case-hardened with self-sufficiency. Now after 27 months of war we have realized our great dependence upon the world for engineering supplies, chemicals, and glassware, and the enormous daily value of the supreme command of the sea. We have learned locality, I think, concerning production of commodities, and that our Government have let the manufacture of some vital necessities slip from our hands, and have let aliens develop our precious resources. Some of us hope for a business Government after the War, with a concern for the things that matter, some hope for inter-colonial preference, and some go as far as to hope for the adoption of a decimal system. I believe that when China does advance and build schools, she will teach English law, language, and colonial policy, and will also adopt the decimal system, and that her preference for decimal manufactures will automatically shut us out from her markets to some extent, but I, for one, think Britain will adopt the decimal system.

With regard to supplies of electrical accessories, one looks with admiration at the way the Japanese have stepped in and tried to remedy the shortage of Western sapplies: she is shipping huge quantities to China at present, and these may be seen on every hand. Some electrical installation materials can still be obtained from Japan at cheaper prices than from Europe before the War, and no doubt she will become a formidable competitor of Germany and Austria in the Chinese market in the future. Let us all hope then that the Old Country will rise to the importance of the Eastern markets, and help to exploit China systematically, for the possibilities are enormous, seeing how small is the total mileage of telephone lines to bridge her vast distances, how small the output of electricity to lighten her gloom, and how few the locomotives to bear the burdens she is willing to produce.

MACHINE-SWITCHING TELEPHONE GEAR.

By F. R. McBERTY, Member.

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SYNOPSIS.

Introductory: Nature of switching problem in telephone exchanges; limitations of manual switching.

Nature of mechanical switching problems; single-row switches; co-ordinate switches; ratchet-motor switches; power-driven switches.

Size and multipling of terminal fields; ratio of movable and fixed terminals; conditions for minimum cost.

Trunking through switches; seeking switches; choosing switches; simple line-switches; trunk seeking; group choosing; number of paths for simultaneous connections; calculation of paths by theory of chance; correspondence between calculated and observed results; practical importance of calculating the traffic-carrying capacity of a machine-switching equipment; lost or delayed calls; standard "rating" of capacity; comparing switching equipments of different types; results of computing by different methods.

Controlling switches; full-automatic and semi-automatic operating; substation number-senders; key number-senders; number-registers.

Call distribution to operators; time of answering; number in team; operator's load.

Description of a machine-switching equipment; terminal fields; finders; selectors; sequence switches; bays; assembly in frames; equipment of switches; motors and power plant; operator's equipment; keyboards; registers; translation of numbers; call distribution—timed distribution and "helping-out"; toll switching.

Traffic between manual and machine switches; incoming junction calls; outgoing junction calls; called-number indicator.

Telephone service in machine-switching systems; accuracy; speed of answering; speed of connecting; comparison with manual service; duration of connection; operator's load; handling time; resting time; comparison of loads observed and computed for manual and machine-switching systems.

Maintenance of machine switches; man-hours per line per year; minimum labour; relation to percentage of errors; classified record of observed faults.

Depreciation of machine-switching apparatus; wear, breakage, deterioration; displacement.

Conclusion.

The desirability of attempting to perform telephone switching by mechanical means has been a moot question amongst constructors and operators of telephone exchanges throughout nearly the entire period of development of exchanges; in general the decision has been adverse by reason of the mechanical imperfection, high cost, and want of adaptability to rapidly changing telephonic conditions which have characterized the available switching machines. The art now has reached such a condition that efforts are rare to maintain either that switching machines cannot successfully perform telephonic switching in all its requirements, or that their cost is prohibitively high. I propose, therefore, to take advantage of the indefinite scope for this paper suggested by the title to sketch the reasons in favour of employing switching machinery, to outline the nature of the switching machinery which is available, and to give some résumé of the improvements and economies in telephone service which may be expected to result from the employment of such equipments.

As an introduction to the problems of machine switching, we may review the operations now necessary in a telephone exchange and the methods of performing them manually. They are, to place a conducting link between a terminal of a calling party's line and the terminal of any party wanted within the telephonic area, to signal the wanted party, and to return the apparatus to normal condition after conversation.

Within 40 years the extension of the circuits to be interconnected has increased from a maximum of a few hundred feet to a maximum of 5,000 miles; the number of telephones to be interconnected has increased from a dozen or so to 10 millions; the time required for the switching operations in local service has diminished from an hour or more to a maximum measurable in seconds. The training of the operator and the development of apparatus and methods suited to her have permitted these changes; but the physical and mental characteristics of the operator have dominated the nature and cost of the apparatus and the arrangement of the plant.

The operator has been needed primarily to perform the physical work of connecting one terminal with, and disconnecting it from, the other. In addition, she has been loaded with the supervision and inspection of the connections, with various discriminatory functions in respect of classes of service, choice of routes and rates, and with various sorts of clerical work. In the present consideration, we are concerned mainly with the physical work of switching. The need for supervision is largely the result of imperfect operation—the telephone user ordinarily wants nothing but an uninterrupted conversation with his correspondent. The discrimination in respect to classes of service, routes, and rates can be performed mechanically, but does not fall within the function of the switching apparatus. The clerical work ordinarily is assigned in machine-switching systems to be cared for by special clerical labour.

In performing switching the operator observes the signal of the calling party, connects her telephone with the calling line, tests the wanted line, connects the calling line with the wanted line, rings the bell at the wanted station, observes the call for disconnection, and removes the connecting means.

Merely to observe a call signal and prepare to act upon it she requires an appreciable time—one or two seconds; to take a plug and insert it into a near-by jack consumes [illegible] necessary to allow her a resting time amounting to 30 or 40 per cent of an hour. The operator has also a limited reach. While sitting, she can reach over a semicircle of about 30 in. radius above knee height; if she is compelled to arise to make a connection, the time consumed, the fatigue, and consequent reduction of load are largely [illegible]

In each of these acts she exhibits inherent and controlling limitations, to which the character of service and of telephonic switching plant have been adjusted. In each of them she is at a distinct disadvantage as compared with a switching machine.

The construction and capabilities of the apparatus which she manipulates are dominated likewise by her physical characteristics. The dimensions and the material of the jacks, plugs and cords, keys and keyboard, are determined by the character of her grasp, and of the forces she exerts in pushing in and pulling out the plugs and working keys; the number of jacks and of junction terminals which can be assembled in a given area is fixed by the dimensions of plugs and keys; and a certain orderly numbered arrange- [illegible] mental effort, must be preserved.

These facts are perhaps so well known to many that their recital is trite, but they are presented to call attention to their effect upon the nature of the telephone plant. They limit the multiple switchboard to about 10,000 lines capacity, thus fixing the largest switching unit which can be operated by a single operator. The time required for noting signals, speaking, and making movements, is so large that a second operator is interposed in a series of connecting operations only of actual necessity, while a third operator can be resorted to only for a limited amount [illegible] may be 8 seconds; in switching through [illegible] The large city-exchange areas therefore have been organized into central offices of about 10,000 lines each, with a maximum switching unit of about 10,000 lines, with junction switching between offices which, regardless of the economies of plant construction, is never permitted to involve more than two operators.

[illegible] of operators, together with those of reserve forces, supervisors, and trainers paid for the times thus [illegible] t feature of telephonic economics. Take, for a rough comparison of costs, the work of the switching or incoming junction operator, which is practically confined to acting upon instructions given as briefly and [illegible] Such an operator can switch about 500 connections per [illegible] for an indefinite period; [illegible] ing per 100,000 connections. In a closer analysis, the comparison is less simple; the switching machine is expected to retire the cost of the displaced manual apparatus, to pay interest and upkeep on itself, and to retire its initial expense during its life. Thus there are brought into the comparison a number of variable factors that, in comparative estimates, are still based largely upon assumptions, which can be adjusted by partisans to demonstrate the case for either manual or for machine switching.

The underlying problem of switching lines together in desired combinations, substantially the same whether by manual or by mechanical means, is to move the terminal of one line calling by chance to the terminal of another particular chosen line amongst a large number and to hold the two in electrical contact for a short period. There is a limit to the time which the switching operation may consume and to the cost of the machine for effecting it. The human motor of the manual switching system has a mechanical advantage over the machine of a controlling nature—the operator can use vision and can plan to determine the course which her hands shall follow in applying the movable to the fixed terminal, and in removing it at the end of connection—and thereby is enabled to move the terminal in three co-ordinate directions as no machine so far designed is capable of doing. In all switching machines the movable terminal is provided with a free and clear path to and from all fixed terminals, and moves in one direction or in two co-ordinate directions in a plane. The human motor, therefore, has been used to operate a number of movable terminals (plugs) over the same field of fixed terminals (jacks) for making a considerable number of simultaneous connections; while the mechanical motor is confined to moving a single movable terminal (brush) over its allotted field of fixed terminals, which must be multipled together before movable terminals in sufficient number to provide for connections occurring simultaneously.

The three limitations suggested—time of switching, cost, and number of machines—have determined the nature of [illegible] series of inventions and developments. Of these the time limit within which the switching operation must be completed has imposed the most rigid restrictions and has resulted in the most various and striking characteristics of switching mechanism.

The obvious method of arranging the terminals in a single row, whether straight, curved, or circular, is immediately open to the objection that the speed at which the movable terminal can be driven is limited by the necessity of stopping accurately upon the required terminal and without a destructive blow. The mass of the moving member cannot be brought below certain limits without sacrificing durability and rigidity; the speed of motion and the accuracy of stopping at the point required is determined by the quickness of action of magnets of which the power diminishes as the quickness is increased. Because of these physical conditions, it has not been found feasible for commercial service to propel the movable ter- [illegible] A number of inventors have solved the problem of driving a movable [illegible] the member being driven at high speed nearly to the desired point, say to the preceding decimal, by the first motor, after which it is connected with the low-speed motor which moves it at a rate suitable for accurate stopping to the particular terminal. By this means, a straight row of terminals up to 500 can be covered within the available period.

A type of quick-acting switch better represented in the art is that having terminals in several rows in a compact rectangular field, the wanted terminal being reached in the field by choosing first the desired row and then the desired point in the row—commonly known as the "co-ordinate" switch. In one form, the switch is furnished with a single movable terminal which is propelled over the field along co-ordinate axes, thus arriving at the most remote terminal by passing crosswise over all the rows and along one of the rows. Of this type are the Strowger switch and the Clement switch, both in extensive and successful use. In another form (the "multiple brush" switch) the movable member carries a number of terminals equal to the number of rows, of which one moving terminal is chosen and put into condition for making contact in the desired row, while the entire group of movable members is propelled over the rows to the desired point in the row. This form of switch is able to connect with the desired point in the field with a minimum of motion, and thus with the same speed permits a relatively massive construction. The form is represented in commercial equipments by two different switching machines, in one of which (the Western Electric system) the desired brush or movable terminal is chosen by moving the brush member bodily into position for contact, whereas in the other (the Lorimer system) all brushes are in contact and one is electrically chosen by an auxiliary switch.

All the co-ordinate switches require two motor elements. Moving at the same rate of speed as a single-row switch, they can cover much larger fields of terminals—it is practicable to reach the most remote of 200 terminal points in one second.

The single row of terminals has been arranged in a straight line, in an arc, and in a complete circle. The straight line is best suited to large switches, for the reason that many rows can be placed side by side in a compact arrangement; the single curved row is suitable only for small switches; the complete circular row is far too bulky for switches of considerable capacity and presents serious difficulties in attaching wires. The rectangular fields take the form of plane surfaces, arcs of cylinders, complete cylinders, and segments of spheres.

It will be apparent that the motor elements required for producing the motion of movable terminals so diverse in extent, rate, and direction must be correspondingly various; but development has favoured two general types, of which one is the ratchet or "step-by-step" motor, and the other the power-driven motor, each with a different characteristic method of control.

Possibly the ratchet motor has the advantage of the longer history; the earliest automatic switching mechanisms were of the same nature as the early Wheatsone telegraphs, electric clocks and like mechanism. Switches which contained only a small number of terminals were intended for location in lieu of operators, in remote places lacking sources of adequate electric power. For such circumstances it is extremely well suited. With the demand for massive construction, high speeds, and large switch capacity, the limitations of ratchet motors have been found serious, and recourse has been had to constantly driven motors to which the moving-switch member is clutched as required. The ratchet motor has the advantage of being quiet, except at the moments of propelling the switch member, which may amount to no more than one or two minutes per day. Aside from the presence of a constantly moving part, simplicity of construction and easy maintenance would seem to be in favour of the power-driven clutch. For such work as is required of a telephone switch, it is a surprising fact that the annual cost of a piece of shafting maintained in constant motion is very little more than that of the same piece of metal still, and much less than the cost of maintaining a more complex form of motor device.

Size of Machines and Number of Multiples.

Reference has been made to the fact that in the case of the machine, unlike the case of the operator who is able to move terminal plugs in three co-ordinate directions and by choice of route to avoid entanglements, a machine of a fairly simple nature requires the provision of a separate field of terminals for each moving terminal. The accommodation of the traffic then requires a sufficient number of multiple fields each with its movable terminal and motor to make and maintain the maximum number of connections simultaneously required in the particular numerical group represented in the field of terminals.

The maximum requirement deviates considerably from the average of the traffic requirements, and the deviation increases very greatly as the group of lines diminishes. This fact under present conditions of manufacture has an important influence upon the number of terminals which may be brought together in a single multiple field, and on the consequent dimensions of the individual machine switch. Conceivably, switches may be built either with a very small number of terminals or with a very large number, still within the limits of mechanical possibility and of the permitted time for the motion of establishing the connection. At one extreme, the large switch, the number of fixed terminals provided and the consequent cost of the multiple field increases enormously, although the number of terminal points actually used remains unchanged—that is to say, although the movable terminal requires only one fixed point for its connection at any time, the remaining terminals stand by as idle but available plant which the earnings of the terminal in use must cover. At the other extreme, the small switch, the necessary provision for the simultaneous connections in excess of the average number, each of which requires a terminal field (which may be smaller), and also a movable terminal member with its motor, results in a prohibitively large number of machines. The motor and the driven member are more costly than a large number of terminals. The machine for maximum economy in first cost must therefore represent a choice between a large number of terminals very inefficiently employed, with a minimum number of motors and movable members very efficiently employed, on the one hand, and on the other a small number of terminals efficiently employed and a large number of

[illegible]

The subsequent cost of maintenance is, however, of [illegible] multiplication of fixed parts.

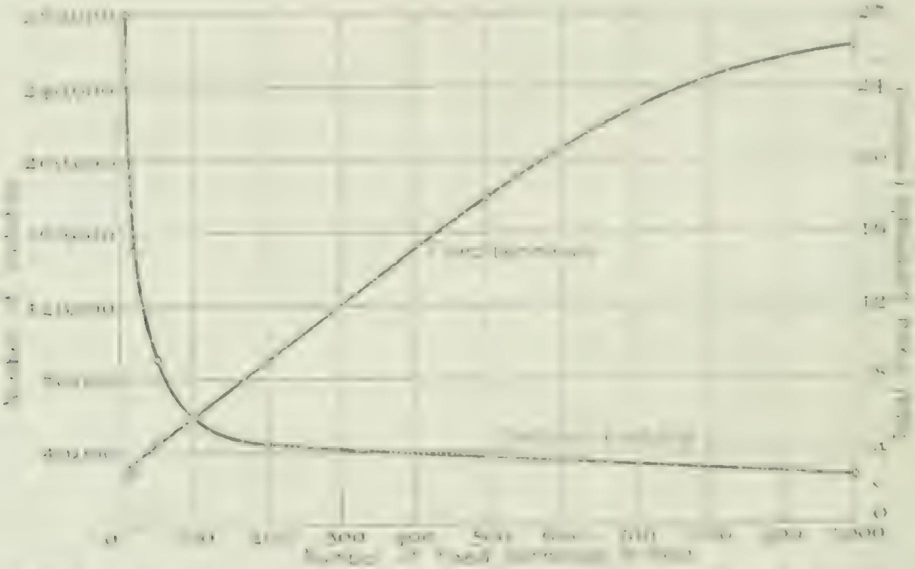
The form and dimensions of the machine, for minimum first cost, depend upon the choice of the material and the means of supporting the fixed terminals, as well as upon [illegible] of the motor and movable members. Proceed[illegible] one extreme to the other of dimensions of field, the nature of the mechanical problems changes strikingly. [illegible] motion from a pivot centre, the range of motion being short and quickly covered. At a certain dimension of field, [illegible] some expedient for moving the [illegible] or the co-ordinate arrangement; and [illegible] to obtain rapid motion and accurate [illegible] in difficulty with increasing dimensions [illegible]

[illegible] the switching machine may be controlled [illegible] respectively, [illegible]

in the choosing-switch or selector, the moving terminal is propelled through a measured distance which is controlled [illegible] bined in the same switch. Nevertheless, the finders commonly require a smaller field of terminals for efficient operation than selectors, and each of the developed machine switching systems contains two forms of switching machine based on this difference of function.

[illegible]

Up to this point, discussion has been confined to the mechanical appliances for moving the connecting terminal over a field of fixed terminals. The mechanical limitations and the costs are such that the switching machine in itself is quite inadequate for interconnecting the lines of even a small telephone exchange. The manual switchboard is as noted limited to about 10,000 lines within reach of the operator with a plug. The largest machine switch so far constructed is limited to about 500 lines within reach of the movable terminal. Recourse is therefore had to combinations of machine switches operating in series, the seekers connecting the calling lines into diminishing groups of trunks finally to the first series of choosers, whence they are distributed under direction of the calling subscriber through continually ramifying groups to the wanted lines. The mechanism for distributing the incoming calls to their destinations in the field of called lines is exactly like that resorted to in the manual system when the single multiple-jack field was outgrown, namely trunking [illegible] line in a chosen group of junctions, which ends in the [illegible] another field of jacks containing the wanted line. As pointed out at the beginning of this paper, the manual [illegible]



[illegible]

The switching machine is free from this limitation and permits the switching of connections through successive junction lines and machine switches to an unlimited extent.

The different groupings of junction lines and the manner of interposing the switching machines for working from one group into another can be best presented in a series of simple diagrams. The movable terminal or brush is represented by an arrowhead, while the multipled fixed terminals are indicated in heavy parallel lines and may be taken as representing, for example, the panel type switch. It is assumed that the arrow can be driven to any contact bar and stopped on it without touching the others.

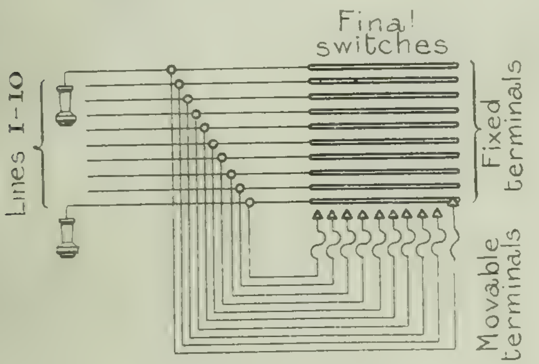


FIG. 2.—Selector on line.

The simplest form of line-switching apparatus is that with a moving terminal for each line to originate calls, and fixed terminals for all lines accessible to each of the moving terminals for receiving calls (Fig. 2). Historically this was the first form. The machine switches in this form are used with extreme inefficiency; in an exchange of ordinary character, each machine would be employed on an average not more than two minutes in the busiest hour. The fact that the size of the exchange is limited to the size of the machine and that a switch is required for each of the lines, has caused its displacement in favour of systems of greater efficiency and larger capacity.

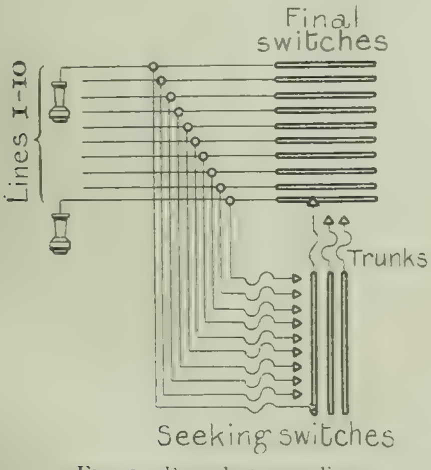


FIG. 3.—Pre-selector on line.

A large economy results from interposing a seeking switch between the calling line and the choosing switch, which then becomes available to all calling lines for completing their required connections. The seeking switch may be attached either to the line requiring connection (Fig. 3), or to the trunk line with which connection is required (Fig. 4). In the first case, the motor of the seeking switch is ordinarily set in motion by a line relay of the calling line; in the second case, the motor is set in motion by a common means made active when any of the calling lines requires a selector. Because of the large number of seeking switches employed in the first case, the cost must be kept low, a condition which excludes large terminal fields and complicated means for keeping the time of search within narrow limits. The finder form (Fig. 4), since the finders are relatively few in number, may be larger and of more costly construction.

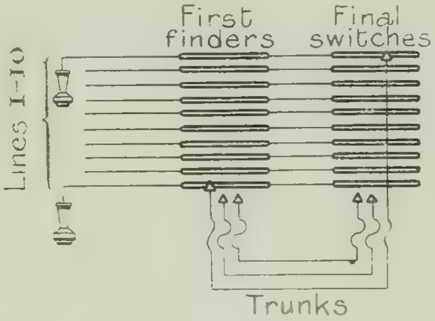


FIG. 4.—Pre-selector on trunk.

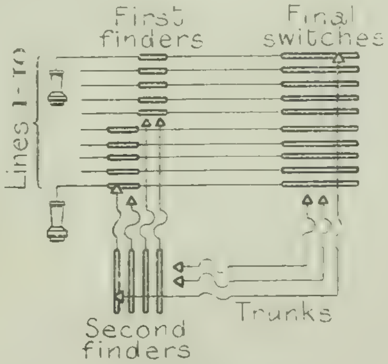


FIG. 5.—Successive seeking.

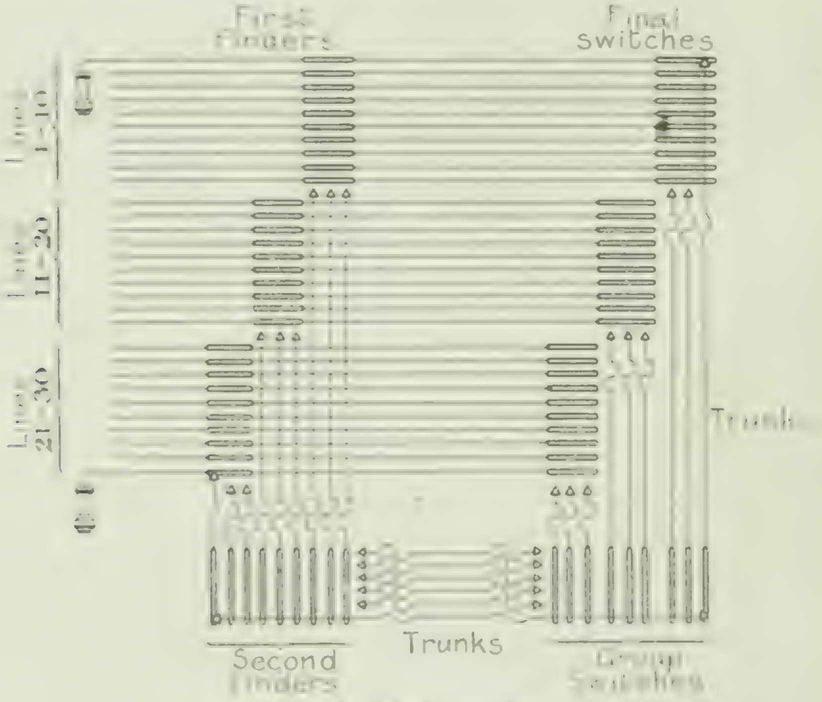
The connection of the calling line with the required trunk line may be made in a series of stages through successive seekers (Fig. 5).

The call-originating lines may then be divided into groups each served by a seeking switch with a relatively small multiple field. Thus, for example, to connect with any one of 100 lines with a single common selector would require either a finder of 100 points, or 10 finders of 10 points each, giving access to 10 groups of 10 lines each, together with a secondary finder having access to the 10 primary finders; while the introduction of a third order of finders would extend the availability of the common selector to 1,000 lines. Since, however, it is necessary to

[illegible]

[illegible] point at which the increase in dimensions of the secondary [illegible]

The function of the seeking switch is to concentrate the connections originating in a large group of lines upon a limited number of the more complex and costly elements involved in the connection, namely, the group-choosing switches and the speech-transmitting and controlling gear. The function of the choosing-switch or group-switches is the reverse—to distribute the traffic from those general and relatively costly appliances to a large number of call-receiving lines—and this purpose likewise is served by one [illegible] In this case, however, since the purpose of the selection is to reach a particular line, the connection into the next group cannot [illegible] two first-described methods of choosing the group require for each trunk a separate movable terminal and motor for [illegible] the double choice in a single machine—one, or at most two motors are required (one for choosing the group and one for choosing the idle trunk in the group), but fixed terminals for all trunks of all groups must be assembled in a single machine. The former plan thus calls for a large number of moving elements very inefficiently used, while the latter plan requires a large number of fixed terminals inefficiently used by a small number of movable terminals. In this case also, the choice of a commercial switching plan is determined by the relative cost of movable and fixed terminals. It is unnecessary to emphasize the desirability of thus concentrating the traffic of the telephone system in the minimum number of machine switches; the extent to which it can be carried determines both the dimensions and number of the switching machines, and thus the cost of the equipment. This concentration has been one of the [illegible] with manual-switching systems. The extent of the concentration, or in other words the relative number of paths through the switching equipment for simultaneous connections, determines not only the cost of the equipment but also the quality of service it is capable of rendering [illegible] as certainly would carry the maximum traffic in the busiest hour ever experienced—but only at high cost. At the other extreme, the switching equipment may be reduced to a point at which, during busy periods, such a large percentage of connections are prevented or delayed by the occupation of all trunks, or of trunks at some place



[illegible]

of maximum congestion, that service is seriously impaired. In planning the switching equipment, the constructor, as well as the purchaser, must make a choice between first cost and quality of service.

For the inventor, the engineer, and the purchaser of machine-switching equipments, the computation of the number of paths from calling to called lines, and the number of machines and trunk links necessary for producing the paths, becomes essential.

Supplying telephonic connections in the community is unlike the supplying of water, gas, or electric power, in which an unexpected increase in the number of simultaneous users results in a drop in potential, which maintains a supply as required, but of inferior quality. It may better be compared with a network of tramlines in which when the existing equipment is filled at any point the excess traffic is stopped and delay and congestion, loss and discontent result. A subscriber calling, either gets through and speaks with his wanted subscriber, or he fails to get the wanted party; the result of failure will be definite loss of revenue for the owner of the equipment coupled with dissatisfaction on the part of the users or a large increase in calling rate resulting from repeated futile calls. Each such repeated call may involve the use of the plant to almost the same extent as a successful and revenue-producing connection.

TABLE 1.

Comparison of Observed and Computed Chances.

Nature of Test	No. of Kinds	No. of each	No. of Trials	No of Drawings	Observed			Computed			Probability (P)
					Number	Times exceeded	No. of Trials	Number	Times exceeded	No of Trials.	
Balls from basket	4 colours	40	10	400	15	1	10	15·4	1	10	0·1
,, ,,	4 ,,	12	50	600	5	6	50	5·9	5	50	0·1
Cards from pack	8	60	100	6,000	10	85	100	10·2	100	100	0·1
,, ,,	8	60	100	6,000	13	8	100	13·2	10	100	0·1
,, ,,	8	60	100	6,000	15	1	100	15·3	1	100	0·1

TABLE 2.

Calls per hour ...	2,796		2,850		4,215		4,269		5,757		5,533		7,065	
Maximum Calls in	O	C	O	C	O	C	O	C	O	C	O	C	O	C
15 sec.	20	21	22	22	26	30	30	30	40	38	37	37	46	45
30 ,,	36	35	38	36	50	49	50	50	68	65	67	63	79	77
60 ,,	68	61	70	62	91	88	91	89	117	117	112	112	140	141
90 ,,	100	86	92	89	133	126	137	127	170	167	165	161	212	212
120 ,,	124	111	121	113	166	162	174	167	227	217	221	209	278	263
No. of lines	633	—	633	—	940	—	940	—	1,261	—	1,254	—	1,573	—

O = Observed; C = Computed.

In the manual-switching system the calculation in advance of the elements for use in common has not been essential. The principal point of congestion has been the called subscriber's line. The common paths in the switchboard are the plugs and plug circuits, which constitute a small factor in the total cost of the exchange, and have been supplied in adequate number readily by manufacturers. Each insufficiency of cords is known to and reported by the operator, and the required connection can be made through an adjacent operator's equipment. In the case of multi-office areas the junction lines are in some cases sufficiently costly to call for consideration of the probable traffic and choking. Two different plans have prevailed in providing junctions under different conditions, of which one was known as the "no-delay" basis. This practice was maintained by one of the largest private companies by recording each failure of an operator to obtain a junction line to a given office, and on the third report of "all junctions busy" to a given office, wiring in an added junction. The practice resulted in a number of junctions considerably in excess of the normal requirements, but by reason of the relatively cheap terminal apparatus involved no large expenditure for idle plant In a number of large multi-office areas the alternative plan has been adopted of closely limiting the number of local junction lines, with the result in one case that between important offices 6 per cent of the busy hour's calls were blocked because all junctions were busy, the number rising in one example to 11 per cent. So far as the author is aware, no definite effort has been made to determine the percentage [illegible] by [illegible] a permissible [illegible] the capacity thereof.

In the [illegible] switching equipment the accurate adjustment of the switching capacity to traffic in [illegible] The number of trunks or junctions linked together to form a through circuit is larger than in manual equipments; the switching mechanisms for connecting the successive links form [illegible] switching equipment the addition of link circuits when later required is more [illegible] the addition cannot be observed with equal facility; the required switching capacity, as made clear in the foregoing pages, largely affects the nature of the mechanism. The planning of machine-switching equipments, and the comparison in respect to performance and cost of switching equipments of different types, require a more accurate [illegible] the traffic-carrying capacity of the equipments than was usual in manual practice. Discussion of relative merits of the several mathematical methods of computing capacity is not within the scope of this paper; but some reference to the practical aspects of the current discussion of methods [illegible]

It must be stated that telephone calls are not originated, or distributed amongst lines, purely by chance, but rather to some extent in accordance with fixed social and physical conditions; nevertheless a large number of calls originating [illegible] given periods of time and as originating and terminating at random in the different numerical or geographical groups of lines. The switching equipment must have a carrying capacity or number of paths for the maximum number of connections required in the busiest moment, [illegible] any group of call-originating lines to any group of call- [illegible] numbers on a basis of averages, but the system so planned would be deficient to the point of practical inoperativeness. Studies of chance are employed to determine the probable deviation from the average. It is not expedient to provide for an absolute maximum of paths, but it is necessary to compute and make such provision that the switching capacity of any portion of the exchange prob- [illegible]

Illustrations of the extent to which the results computed [illegible] with the results observed in trials of chance [illegible] f telephone traffic will be of interest.

An [illegible] of the probable maximum deviation above [illegible] r and the excess actually observed in [illegible]

[illegible] occurrence of originated calls during the busy hour affords a fairly good test of correspondence; the number and sequence of originated calls will differ, however, from pure chance distribution by reason of the occurrence of peak loads at certain times due to social conditions, to differences in calling rate of lines, to recalls in close sequence, and to the exclusion of calling by the subscriber during speaking. Table 2 shows for a large central-battery manual board, in one column (O), the flat-rate arriving calls recorded during intervals of 15 seconds and grouped together in periods of different duration from 15 seconds to 120 seconds, and in the adjacent column (C) the corresponding number of calls computed for the probability that it will be exceeded once during the observed busy hour.

In calculating the number of junction lines required for accommodating a known amount of traffic, complications arise in addition to those affecting calls originated, of which perhaps the principal is the deviation from average holding time of the junction. In Table 3 comparison is made of the number of junctions actually used simultaneously in each of 11 groups of junctions between different manual offices, carrying different numbers of busy-hour connections, the efficiency of the junctions being expressed in percentages, with the computed number of junctions and the corresponding computed efficiencies. The holding time for the observed calls averaged about 110 seconds, the deviations being unknown; the holding time for the computed calls was assumed to be 120 seconds. The junctions observed were ample in number, and there was in fact no blocking or delay of the connections, while in the case of the computed calls one call lost or delayed by reason of all trunks being busy, is assumed for each busy hour—in other words, the computed number of trunks required would be once exceeded in each of the busy hours. In view of the probable differences between the actual and the assumed conditions, the correspondence between the observed and computed results is fair.

TABLE 3.

[illegible]	[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible] One Delay [illegible]	Efficiency [illegible]
60	[illegible]	[illegible]	5	[illegible]
[illegible]	[illegible]	[illegible]	11	[illegible]
[illegible]	[illegible]	43	[illegible]	[illegible]
[illegible]	[illegible]	47	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	44	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	62	74	81
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2,000	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	142	71	[illegible]	[illegible]

In a paper [illegible] reproduced as

[illegible]

Fig. 7) showing for 8 busy hours the numbers of connections mechanically recorded in a group of 10 trunks in an automatic telephone exchange. In order to discover the correspondence between these recorded and computed results, Table 4 has been calculated. In comparing the recorded with the computed numbers, account may be taken of the fact that the duration of the recorded calls deviated considerably from the average 81·25 seconds, while the computed numbers do not; for example, in column 3 the 60 connections recorded in Trunk No. 1, if all were of average length, would occupy 4,875 seconds in the hour. To the extent to which the actual connections have a duration less than the average they will be concentrated in the earlier trunks of the group (first tested over) and therefore will not appear in the trunks placed further along in the group. The fact is noteworthy, however, that the total connections observed in no cases required in fact more than 10 trunks, while the computed numbers led to exactly the same result with the exception of those in the third column, in which as computed the 228 connections in the busy hour once would have required one additional trunk.

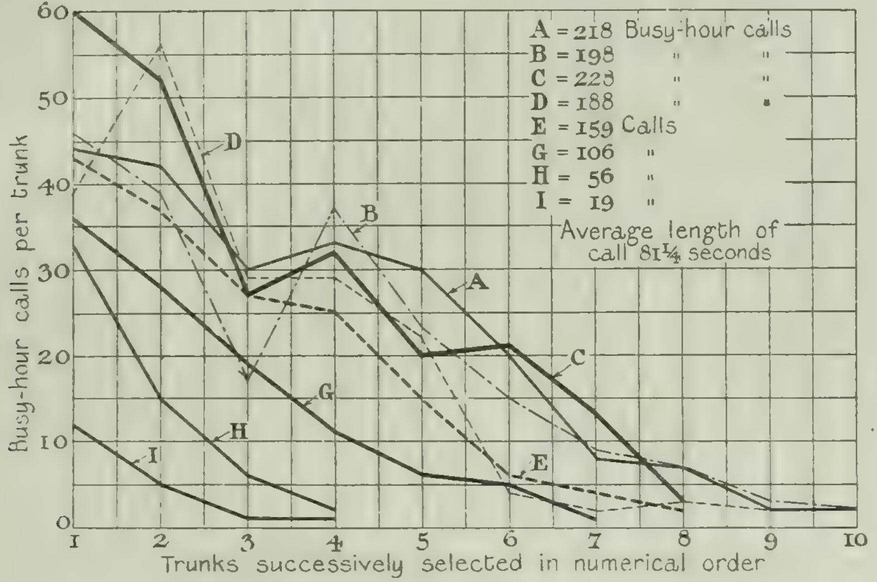


FIG. 7.—Observed connections in Strowger trunks.

TABLE 4.

Tests	A 218 b.h.c. 4·92 av.		B 198 b.h.c. 4·47 av.		C 228 b.h.c. 15·14 av.		D 188 b.h.c. 4·24 av.		E 159 b.h.c. 3·59 av.		G 106 b.h.c. 2·4 av.		H 56 b.h.c. 1·26 av.		I 19 b.h.c. 0·43 av.	
Trunk Employed	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
No. 1	44	44	46	43	60	44	39	43	43	43	36	40	33	32	12	15
2	42	42	39	42	52	43	56	41	37	39	28	31	15	16	5	4
3	30	38	17	36	27	39	29	34	27	31	19	19	6	6	1	1
4	33	32	37	29	32	33	29	27	25	22	11	10	2	2	1	
5	30	25	23	20	20	27	22	18	15	13	6	5				
6	20	17	15	13	21	18	4	12	6	7	5	1				
7	8	10	9	8	13	12	2	7	4	3	1					
8	7	6	7	4	3	7	3	3	2	1						
9	2	3	3	2		3	2	2		0						
10	2	1	2	1		1	2	1		0						
	218	218	198	198	228	227	188	188	159	159	106	106	56	56	19	19

The correspondence between the number of switches required by traffic of given amount and character as observed and as computed from observed duration of conversation, is shown in Fig. 8. The observations were made in a semi-automatic machine-switching equipment known hereafter as "I." The total number of connections during the period of observation was 846, the average holding time per connection being 55·9 seconds. The equipment employed contained 22 trunks in a group; the

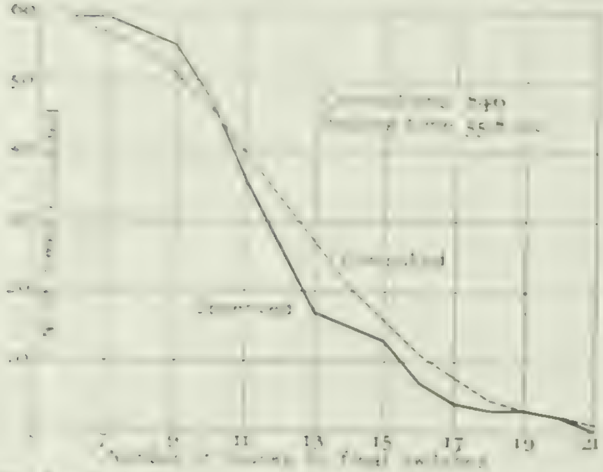


Fig. 8.—Comparison of observed and computed trunk efficiency.

22nd trunk was not required during the period of observation, though 21 trunks were required. As computed for one call lost in the period, 22 trunks might have been once exceeded. The correspondence between observed and computed results is noticeably close.

Practical Bearing of Computations of Probable Traffic.

Reference has been made in the foregoing pages to the percentage of calls lost or delayed by reason of deficient (number of switching machines). The expedient for economy common practice permits the calculation of a switching capacity of the necessary trunk lines and switching machines which will be adequate for all but a certain peak of load; this peak of originating load unprovided for will consist in calls delayed, or blocked, by a busy-back signal. The cost of accommodating the peak sufficiently—when the day's traffic curve shows sharp peaks—may be considerable. Fig. 9 shows the number of switching machines (and trunk lines) for two equipments otherwise identical, the capacity of one of which is such as to produce a delay or loss of one per cent of the day's originated calls in the switching equipment (excluding the loss at the called party's line) while the other gives the capacity which would produce about 0·1 per cent loss in the day's calls. The curves are figured on the assumption of four orders of switching machines, two busy hours per day (80 per cent of the peak traffic being taken as a busy hour), one-eighth of the day's calls in the busy hour, and a holding time of two minutes.

A system equipped in accordance with the lower of these curves would produce a number of "trunk-busy-tests" during the busy hour equal to about 4 per cent of the originated calls. This rate of loss or delay may be compared with accepted manual practice, in which a busy-hour loss at the called party's line amounting to 15 per cent is not unusual; and with the official report for the Post Office system for 1913 noting the percentage of "engaged calls" as 17·4 per cent.

In a switching system in which the testing of trunks at a given group is not prolonged or repeated, an advancing connection which encounters all trunks busy is blocked and lost. Therefore the switching capacity represented in the lower curve would result in 4 per cent of calls lost and returning the busy-back signal during the busy hour. When registers are employed for recording the number wanted and governing the selection and the testing of trunks, the test of engaged trunks may be prolonged or repeated until a trunk becomes available; the call is then merely subjected to a delay which is negligible in the time of total completion. Table 5 below shows for a system constructed for the repeated testing of busy trunk groups and for the switching machines of a single group employed

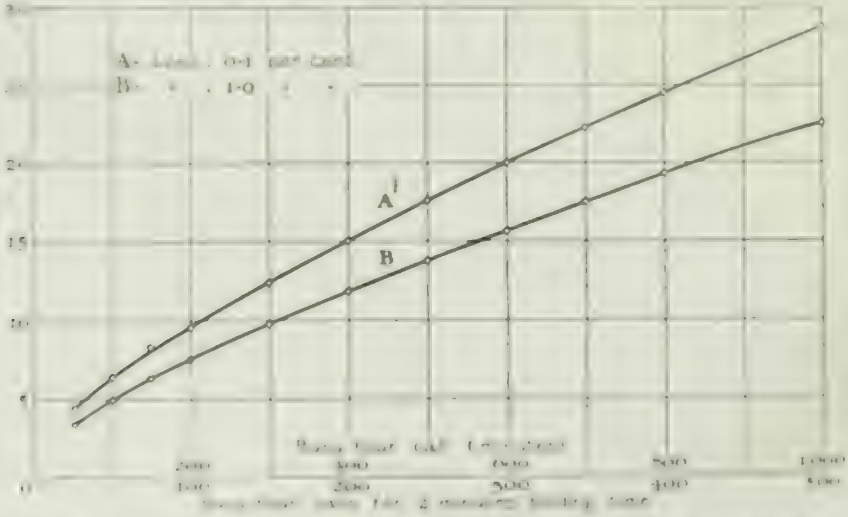


Fig. 9.—Number of trunk circuits for different percentages of calls lost or delayed.

at four different percentage efficiencies, the percentage of busy-hour calls which would wait longer than 12 seconds. In a machine-switching equipment "G" with such registers, it was found by test that the number of final switches could be reduced to the extent of 25 per cent before the delays imposed upon connections in progress because of repeated testing to obtain an idle line switch became perceptible to the users.

Table 5.

Percentage of Calls lost or delayed.

Efficiency %	Calls Lost on Test %	Calls waiting longer than 12 secs. %
0·55	3·4	0·45
0·65	8·3	1·4
0·70	12·2	3·8
0·80	23·4	9·0

Comparing Different Switching Equipments.

Since the switching capacity of the system affects the cost of the equipment to a very considerable degree, comparison of machine-switching systems of different types necessitates recourse to some method of estimating the capacities or the percentages of busy tests (lost or delayed calls) in trunk groups of different numbers and for different processes of selection. For such a purpose the mathematical computations based upon traffic assumptions uniform for the systems compared are easily applied and highly significant.

Table 6 exhibits the different numbers of machines provided and the different percentages of calls lost or delayed in similar switching equipments computed according to the several methods which have prevailed up to the present. It would seem highly desirable that a standard method of computing the switching machines in an equipment should be agreed upon as a basis of "rating" or comparing systems of different types.

Table 6.

Machine-switching Equipment for Lines 5,000, *Busy-hour Calls* 6,000, *Holding Time* 2 *min.*

Method of Computing Machines	Machine Switches Required	Delayed Calls Per Day	Delayed Day's Calls %	Delayed Busy Hour Calls %
G. P. O. (Chart)	1,788	278	0·58	2·3
$i = nt + 2{\cdot}8 \sqrt[3]{nt}$	1,687	364	0·76	3·1
W. E. Co. ...	2,150	48	0·1	0·4

Controlling the Switches; Full Automatic and Semi-automatic Systems.

The manner of controlling the movements of the two types of switches with ratchet and power motors are characteristically different; the ratchet motor impulses of current are produced by the controlling means which operate the motor magnets of the switches successively step-by-step, advancing the moving member to an extent corresponding to the number of impulses; in the power-driven switch, the switch is set in motion, and in its motion transmits back to the controlling means impulses of current which measure the progress of the switch and enable the controlling means to stop it when the desired displacement has been produced. The employment of the ratchet motor driven by a succession of current impulses involves a stoppage of the switch at each impulse, and thus tends toward the reduction of mass to permit prompt stopping and starting. The second named type, which is known as the revertive impulse control, permits an uninterrupted motion of the switch parts, and so permits the employment of relatively large masses, high speeds, and extensive movements.

The standard form of controller for ratchet motors is a break wheel driven at a regulated speed which produces successive interruptions of current to the required number in the circuit containing the motor magnet. The revertive impulse type requires as a controlling device some form of magnet-driven apparatus which counts the impulses measuring the progress of the switch and breaks the circuit of the motor or clutch at the correct number.

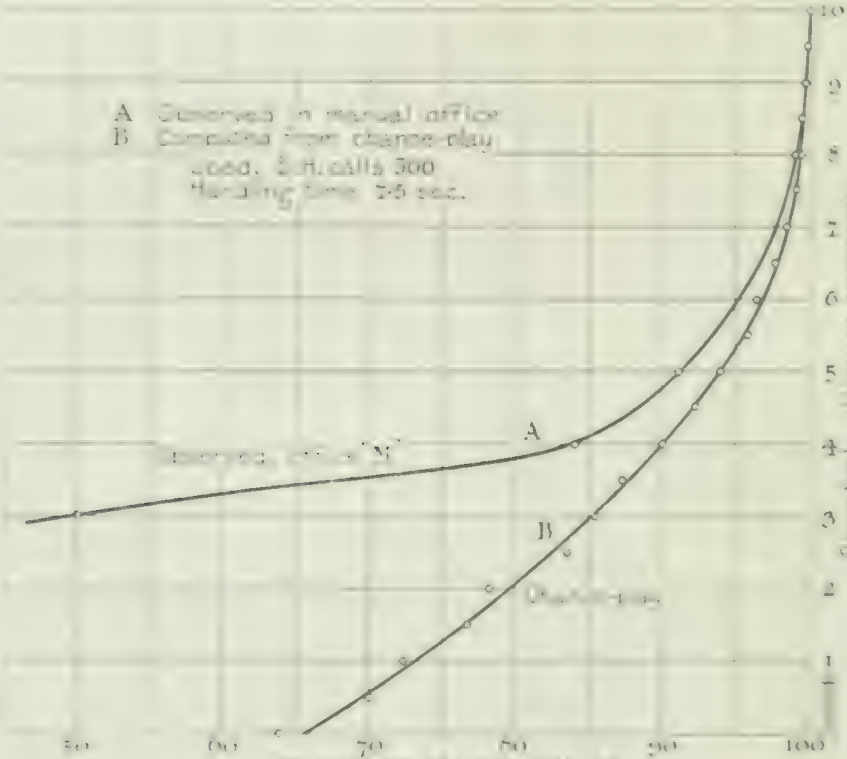
The control of the switching machines may be exercised either by the subscriber himself, furnished with a number-transmitting dial, or by an operator acting under the subscriber's direction by telephone.

For use at the subscribers' stations the spring-driven governing break wheel seems rather to have the advantage in point of simplicity and economy as compared with the magnet-driven escapement. When the controlling apparatus is located in the central office, however, the conditions are reversed. The advantages of both methods are combined in a register or secondary controller on the one hand set by the subscriber to the desired number and in turn controlling the switching machines by reverting impulses. The register in its number-receiving functions may then be best adapted to the conditions of control from the subscriber's station, while in its machine-controlling functions it may be suited for governing the switching machinery.

When the manual switch-controlling mechanism is located at the central office it takes the form of keys corresponding to the numbers like those of a typewriter which can be manipulated with great facility and accuracy. To transmit a five-digit number by means of a dial sender requires about 6 seconds; to set up a like number on keys requires no more than 1 second. In several semi-automatic switching systems the keys directly govern the impulses distributed to the switching machines. Since the operator can dispose of connections more rapidly than the switching machines can perform the numerical and junction selections, two or more sets of keys are furnished for each operator which she may use in succession. In the system of the offices G, I, J, and K, and others later referred to, a single set of keys placed before the operator is associated with several sets of numerical registers, any of which may be set to position corresponding with the numbers of the keys depressed; and the registers free themselves when set from the keys and [illegible] have [illegible]

[illegible] or by means of the number-transmitting dial at [illegible] working in which the registers are set by the operator's keys to the full automatic working in which they are set by the subscriber's station instrument; or for the employ- [illegible]

but very [illegible] because of the delays and [illegible] call distribution. In machine switching, the same mechanism collects the calls from a large number of lines, concentrates them upon a limited number of trunk circuits, and brings them before a limited number of operators in charge of those trunk circuits. The distribution of calls to operators may alter the choice of machines and groups to some extent. The trunks ending in seeking switches are occupied for the full holding time of a connection and hence must be available in a relatively large proportion to the calling lines. It is not desirable to carry the equable distribution of traffic amongst the trunks to an extreme by reason of [illegible] the distributing machinery. The operator, however, is occupied only a few seconds with each connection; it is necessary to bring such a large number of incoming calls to each operator as to keep her fully occupied, and to distribute the incoming calls equably amongst such a large number of operators that none may be overworked, and no calls may be unreasonably delayed. This condition alters the economic relations in such a way as to make it desirable to bring a [illegible] operator up to her full capacity, which may be about five [illegible] the load is the delay imposed upon the individual subscriber's call before it receives attention, which can be



[illegible]

Operating the registers or switching machines directly from the subscriber's station very little affects the nature [illegible] the machine-switching equipment and the [illegible]

[illegible]

kept down only by reducing the load on the operator and so increasing the wage cost per connection, or by distributing calls to a larger number of operators and thereby increasing the quantity of distributing machinery. The standard of promptness in answering a subscriber's call has already been fixed by experience with manual systems and cannot now be exceeded. This service is of the character in which averages are not particularly significant, but extremes determine the character of the service. The aim of good manual practice is to answer the calling subscriber in an average time of 3½ seconds, with no more than 5 per cent of the calls delayed more than 10 seconds.

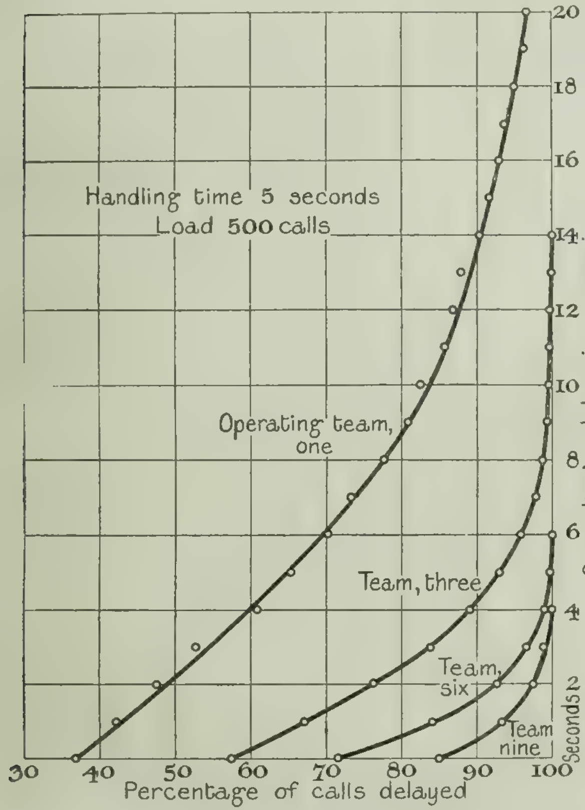


FIG. 11.—Call distribution. Relation between waiting time and number of operators in team.

The collection of exact data for comparison of different methods and degrees of call distribution amongst operators is difficult by reason of the great number of observations required and the rapid changes in conditions which take place during the test. Fairly close correspondence is found between observed results and chance plays, and the latter method is therefore valuable for determining the effects of call distribution. Fig. 10 illustrates the correspondence between chance plays and the results observed, for example, in the manual switchboard "M" when the operators were specially loaded to 300 calls each in the busy hour, with team work amongst three operators. The operator's delay in answering a call in a manual switchboard is composed of two factors, of which the first is a nearly fixed minimum time of rather more than 2 seconds for observing the call signals, plugging into the calling line and connecting her telephone; while the other is the wait imposed while the operator serves other calls, which increases with increasing load. The inclination of the curve of observations therefore tends to the horizontal towards the left. In the case of the curve of chance plays the constant factor for physical work is not present. If it were added the chance curve would be horizontal for a large percentage of the calls at about 2·5 seconds, while the rising portion would correspond even more closely with the curve of observations. This chart can therefore be regarded as showing a close correspondence between the observations of traffic and pure chance plays for the delays caused by calls waiting for one another during rushes.

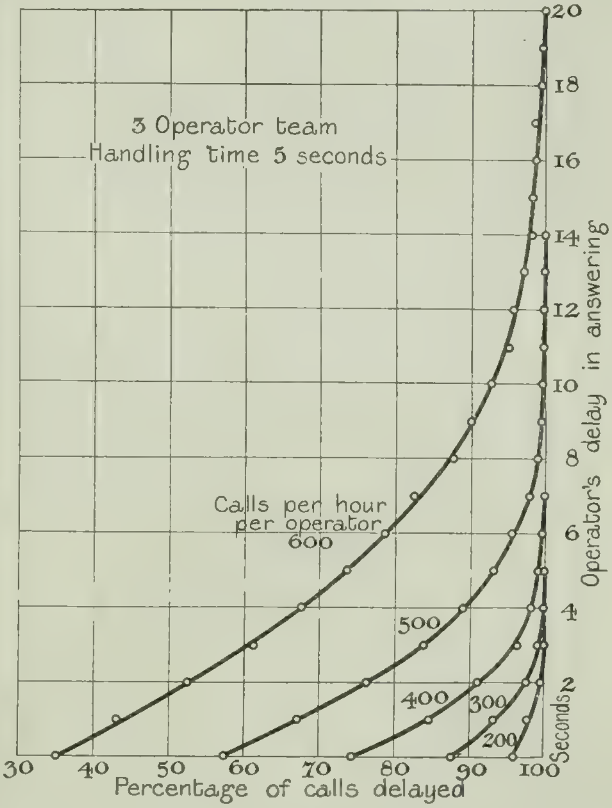


FIG. 12.—Relation between busy-hour load and subscribers' waiting time.

Figs. 11 and 12 were plotted from a large number of similar chance plays, for an assumed handling time of 5 seconds per call. Fig. 11 shows the percentages of calls which are delayed different numbers of seconds by reason of rushes of calls during the busy hour distributed as equably as possible amongst operators working in teams of different numbers from one alone to nine. Fig. 12 shows the relation between subscribers' waiting time and different loads per hour per operator for a team of three operators to whom the calls originating by chance are distributed as equably as possible, the mechanism being assumed to pass the call to the operator's telephone as soon as it is free. The charts indicate that a high grade of service can be attained consistently with a high load

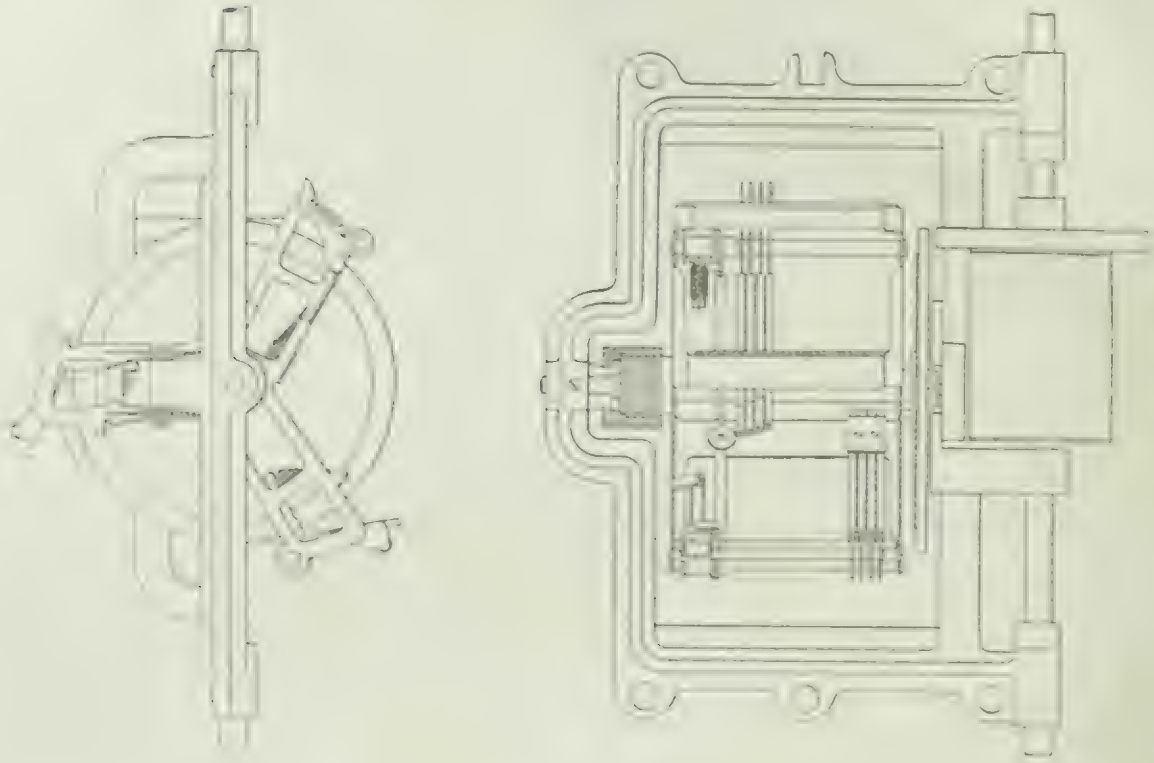


Fig. 14.—Finder brush.

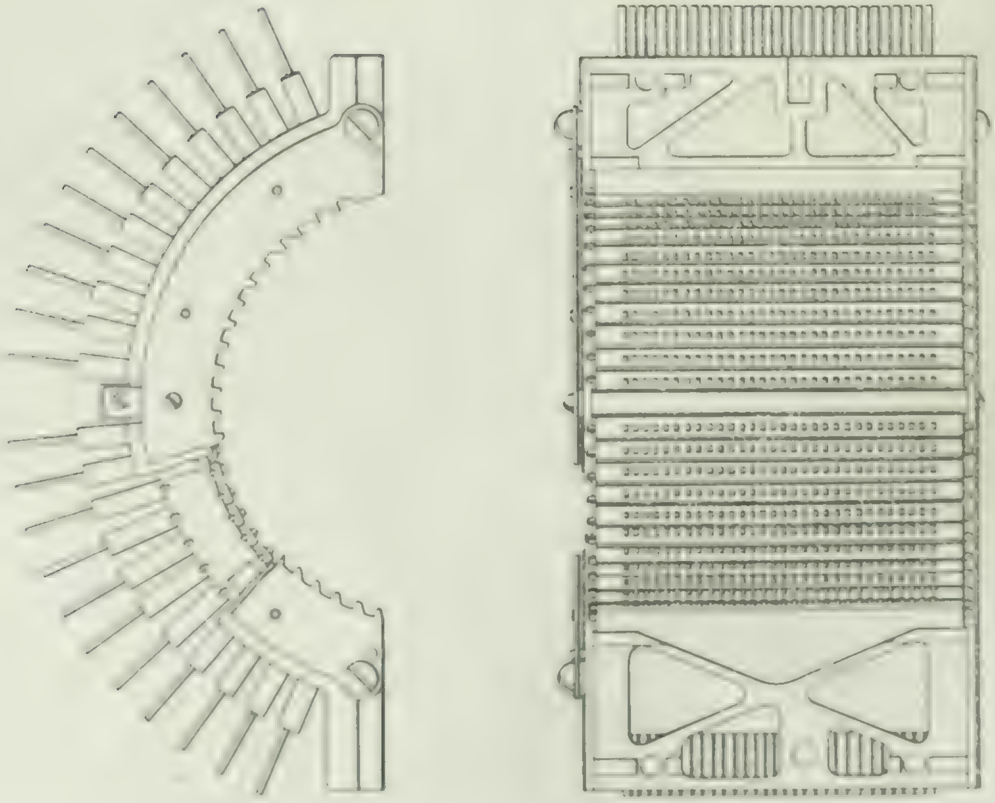


Fig. 15.—Terminal field.

upon each operator, by providing for connecting any call originating amongst two or three thousand lines with any of six or more operators. To perform such a distribution requires seeking switches of large switching capacity.

Description of Automatic-switching Plant.

The results of the foregoing studies and conclusions have been embodied in a number of machine-switching plants, of which one—a semi-automatic equipment for an exchange area in France—will be described here in some detail.

The mechanical switches are of three varieties—the seeking switch or line finder, the choosing switch or selector, and the sequence switch, which last is an appliance for performing a series of shifts of the circuits connected with either of the other appliances for the performance, one after the other, of its several functions. All the switches are driven from a common electric motor through constantly running shafting and magnetic clutches.

The terminal field (Fig. 13) of the switching machine is a segment of a cylinder, in the axis of which the moving brush member is pivoted. The terminals are square bronze wire, presented end-on in the cylindrical surface, with their outer ends projecting radially for attachment to the multipling cables. The terminals are embedded in plates of electrose, which are assembled parallel to the axis in a rigid frame. The terminal-field unit is known as an arc.

A number of these arcs are mounted close together upon one face of a narrow rectangular frame of angle iron; the movable members or brushes with the power clutches, carried in independent small frames, are mounted upon the other face of the frame. The arcs in one frame are multipled together by means of ribbon cables, each cable connecting in multiple those plates of all the arcs which lie in the same radial plane, and ending in a row of soldering terminals at the upper end of the frame (Fig. 15). The frame of angle iron with its assembled arcs and cables is known as a bay of switches.

The bays are mounted in upright position side by side on girders of channel iron to the number required; the permanent cable connections are made by cables lying horizontally upon supports across the tops of all the bays, the fan wires of the cables being connected to the soldering terminals. As many bays—that is, the fields of as many machines—as required thus may be connected permanently in multiple.

The ribbon cable referred to is composed of tinned copper wires as warp, bound together by a woven woof of silk; this ribbon is folded into a flattened helix of which one edge of each turn is sunk between adjacent plates of an arc, while the other edge of the same convolution is laid across the row of terminal pins in the plate adjoining it. The weaving is interrupted along the portion of the ribbon which lies in contact with the terminals to leave the wires bare at those points, and the bared wires fall into notches sawn in the ends of the terminals and are soldered into them. The successive turns of the helix bring the ribbon into similar positions upon all the terminals, and thus bring corresponding wires into connection with corresponding pins in all the arcs.

The wires in the ribbon all lie side by side (not twisted) and thus are susceptible to considerable mutual induction. The wires of certain pairs are therefore transposed in relation to their neighbours at the point where they are connected with the horizontal cables at the top of the frame. The unbalanced capacity can by this means be

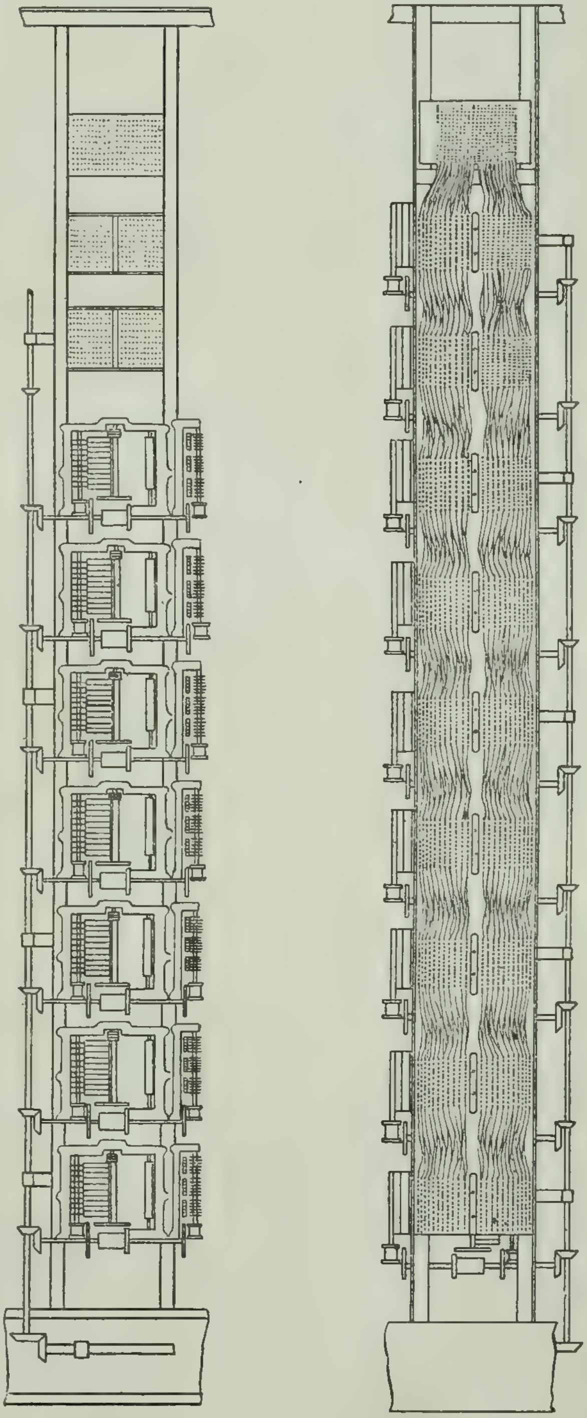


Fig. 15.—Bay.

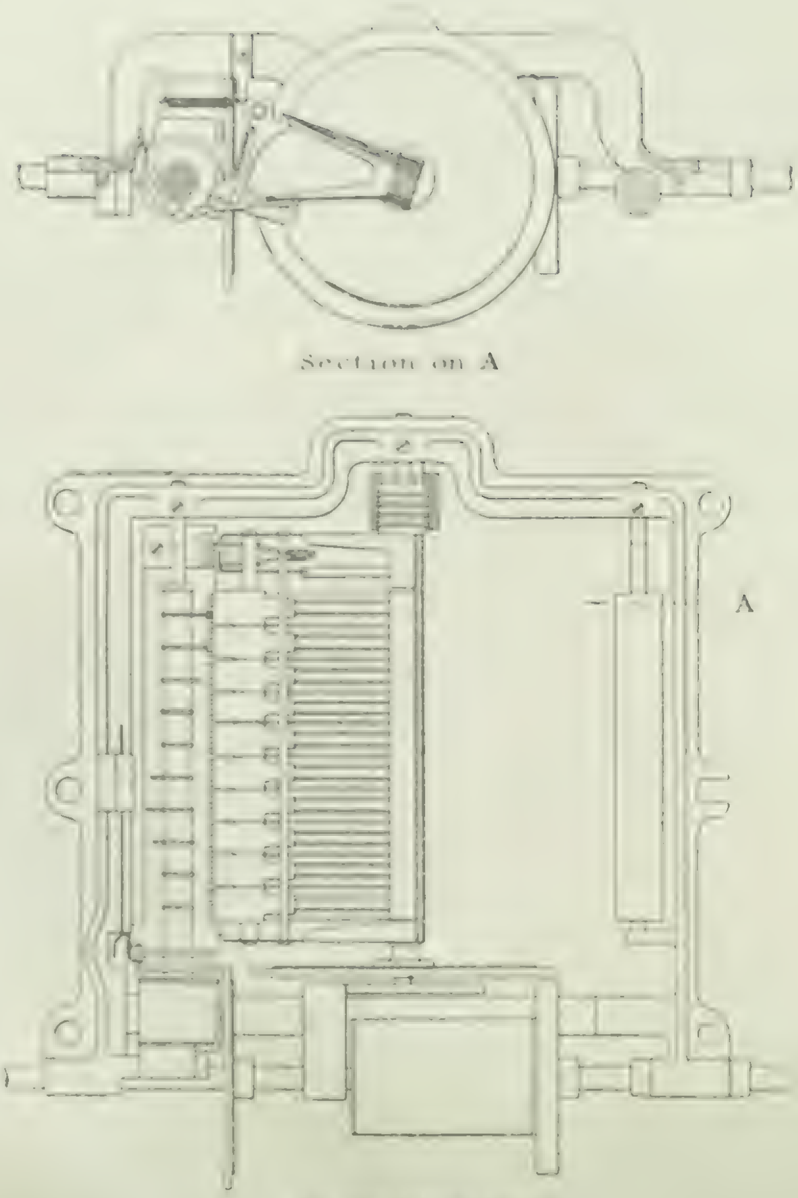


FIG. 16.—Selector Switch.

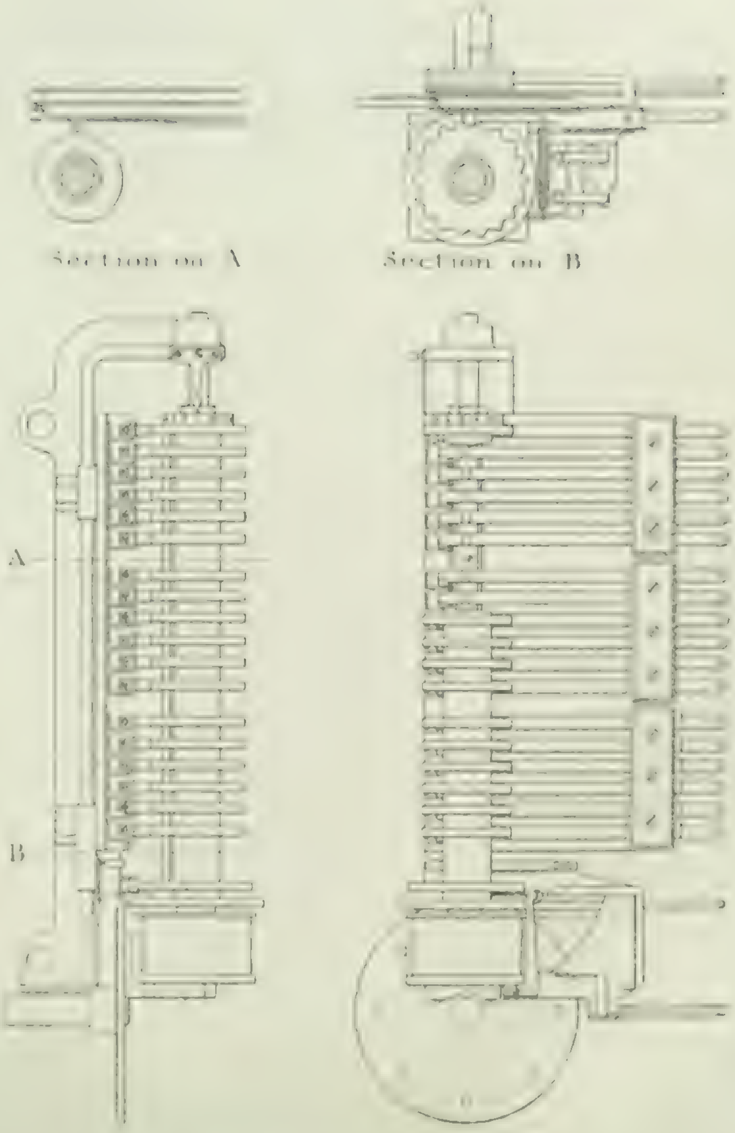


FIG. 17.—Sequence Switch.

so reduced as to permit the multipling together of 500 machines or more without producing troublesome cross-talk.

The multiple field of the line finder numbers 60 sets of terminals, mounted in 20 plates, each containing 12 sets of terminals; in relation to the brush member, it can be regarded as having three horizontal rows of sets of four terminals for 20 lines in each row and, therefore, as containing terminals for 60 lines. The field of the selector is composed of 22 plates of 30 terminals and may be regarded as comprising 10 horizontal rows, each having 22 sets of three terminals and, therefore, accommodating 220 lines in 10 groups of 22 each.

The movable brush members of the finder and of the selector differ in construction. That of the finder has three sets of four brushes, the sets being carried in a star-shaped frame in which the brushes have an angular separation of 120°, and a longitudinal separation such that the three sets pass over the three different horizontal rows of lines; the corresponding brushes in the three groups are connected together in multiple—in effect they are three multiple movable terminals, of which two are in the air and one is sweeping over its particular row of lines, with the result that in one complete rotation, a set of brushes makes contact with the terminals of every line (Fig. 14).

The motor element of the finder consists of a magnetic clutch engaging a friction wheel on a short constantly-rotating horizontal shaft. All the individual shafts of the switches in a bay are geared through small mitre gears to a vertical shaft carried in bearings fixed to the side of the bay, which vertical shaft is in turn geared at the bottom to a horizontal shaft in the channel iron upon which the bays are mounted.

To return to the magnetic clutch—the lower end of the spindle of the brush frame carries a soft iron disc connected through a flexible bronze diaphragm with the spindle; beneath the edge of the disc on the rotating shaft is a soft iron wheel, fixed to a tubular core surrounding the shaft, which is encircled by a magnet winding. The current in the motor coil or "power magnet" magnetizes the wheel, which pulls down the edge of the iron disc into contact with itself and, by its frictional and magnetic engagement, sets it in rotation, driving the brushes over the terminals.

At the top of the arc is fixed a segmental plate having a tooth above each row of terminals; the pivot rod of each brush group carries two pivoted levers, one of which is furnished with a roller which drops successively into the notches corresponding to the rows of terminals, and the other of which makes electrical contact with the tops of the teeth. The contact-maker maintains the current through the motor magnet as long as it touches a tooth, and during the same time the roller is riding over a tooth; these two members are in such position relatively to the contact faces of the brushes that the clutch can be released only when the brushes have been brought to rest accurately on the terminals, in which position the roller thereafter holds them. Beneath the edge of the disc and at the rear, in a position 90° from the friction roller, is a brake magnet; current is supplied to this magnet at the moment of stopping, thus facilitating the stopping of the brushes with very slight overthrow and without a destructive blow.

The movable member (Fig. 16) of the choosing switch or selector also carries multiple brushes, one set of brushes for each row of line terminals, with a mechanism for putting into action any chosen set of brushes. Ten sets of brushes, corresponding to the terminals of the 10 horizontal rows of lines, are mounted in the same brush frame and are permanently connected in multiple; all brushes are normally held back out of position to contact with the terminals, by engagement with pivoted latches of hard rubber. Upon pulling any latch outward, the corresponding set of brushes will be released and will spring into position to sweep over its row of line terminals.

The brush-choosing mechanism is placed at the left side of the machine; it consists of a spindle connected with a magnetic clutch at its lower end and carrying 10 projecting fingers helically arranged, in such a way that in all positions excepting the normal position, one of the fingers will be thrust out into the path of one of the brush latches. The spindle carries near the bottom a star wheel acting upon a contact-maker to produce one period of contact in the act of bringing each successive finger into position before the brush latches. At the right side of the machine is a vertical roller, placed in such position that as the brush frame moves past it, the brushes roll over it and thereby are thrust into engagement with their latches. The function of the trip spindle at the left is to release one set of brushes; that of the roller at the right is to push the released set into re-engagement with its latch.

The brush frame carries a contact-maker engaging teeth in the segmental toothed rack on the terminal arc as in the finder. This contact-maker or interrupter may have only the function of maintaining the motor circuit until the brushes are centred upon the terminals, or the additional function of producing a reverting impulse in a controlling circuit for each set of terminals passed over, and so measuring the progress of the brush frame over the terminals.

In operating the switch, current is first applied to the clutch magnet of the trip spindle, setting the spindle into rotation; as each trip finger is moved to position in the path of the corresponding brush latch, the contact-maker on the star wheel sends an impulse of current to the distant controlling apparatus; the magnetization of the clutch is maintained until, after a sufficient number of impulses have been transmitted, the current is broken from the controlling point, when the motion ceases and the desired trip finger is left in position to release a brush. Then the clutch magnet of the brush frame is magnetized, the brush frame is moved from its normal position, one of the brush latches engages the presented trip finger, the corresponding set of brushes is released and these brushes are driven over a row of terminals until the desired point is reached, when the clutch magnet is de-energized, the brake magnet is excited, and the brushes are brought to rest and held on the desired terminals. For resetting the machine, the clutch magnet is again excited and rotates the brush frame past the resetting roller (thereby relatching any released brushes) and around to the normal position, at which point the interrupter roller touches a contact piece and cuts off the current to the clutch magnet.

Sequence Switches.

The method of switching by means of power applied through a magnetic clutch is further made use of to shift the controlling circuits of each of the switching machines and to perform other functions [illegible] the sequence switch. [illegible] from the [illegible] and [illegible] switches in that it controls a considerable number of circuits [illegible] without shifting them [illegible]. The sequence switch consists of a number of groups of switch springs and contacts which bear upon the edges of insulating cams carried on a spindle operated by a magnetic clutch engaging the same power shafting which serves the selector. A sequence switch is mounted beside each selector; it shifts the connection of the trunk circuit first to the motor of the brush-tripping spindle, then to the motor of the brush frame, then to the brushes themselves when the connection is completed; and also at the final switch it is made use of to control also the connection and disconnection of the ringing current, the control of seeking branch trunks, the closing of the circuit through for conversation and the restoring of the switch after disconnection. Since its movement is derived from a constant, steady source of power, it is used to produce accurately timed periods of break or closure in circuits, and so by preserving a rough synchronism to permit the performance of a series of operations over a single circuit.

The bays of machine switches are erected upright side by side on 8-in. channel iron bases and are supported and connected at the tops by angle iron framework (Fig. 18). The panels of bays are arranged in mutually supporting pairs connected by stiffening framework at the top. The terminal arcs with their cables are on the inner faces, and the shafting and switches are on the outer faces of each pair. Pairs of panels are assembled to the required number, parallel to each other and crosswise to the room, to obtain good illumination and to facilitate the arrangement of cabling.

Fifteen line finders are mounted in each bay. As the average traffic is such as to require 10 finders for each group of 60 lines, the upper 10 finders of each bay are multipled together and a connecting rack at the top to serve a group of 60 lines; the upper 10 finders of the adjacent bay are similarly multipled together and serve another group of 60 lines, while the lower five of the two adjacent bays are also multipled together and so serve a group of 60 lines. The point at which the multipling is discontinued in any bay can be varied to suit the traffic of the particular line or trunk group—that is, in cases of groups of lines having a lower calling rate, a single bay may be divided so as to furnish two groups of seven and eight, or one group of five and one of ten. In the case of groups of lines having exceptionally high calling rates, the [illegible] bay of 15 finders may be assigned to the single group of lines.

The motor for driving the group of bays assembled in [illegible] panels placed in line is located between the panels (Fig. 19); it drives the horizontal shafting through an en- [illegible]

The relays which control the selectors are mounted in racks (Fig. 20) at the ends of the panels, the frames being entirely independent to avoid mechanical vibration.

A $\frac{1}{8}$ h.p. enclosed motor is employed, wound for 220 volts and running at 1,100 r.p.m. The common horizontal shaft makes [illegible] r.p.m.; the individual shafts of the finders and group selectors make 28 r.p.m. The line finders thus are driven over terminals at the rate of 20 terminals per second; the trip spindles of the group-choosing selectors (which transmit impulses to the controlling apparatus)

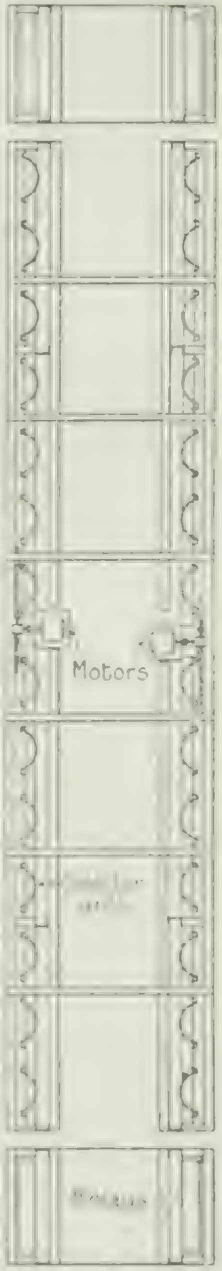


FIG. 19.

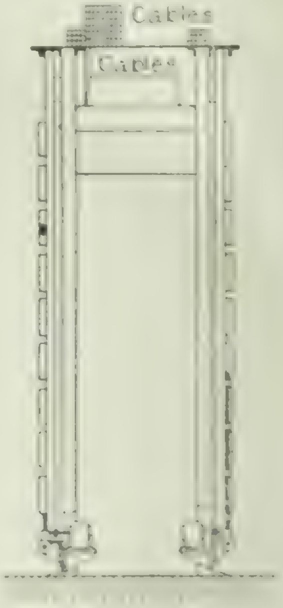


FIG. 18.

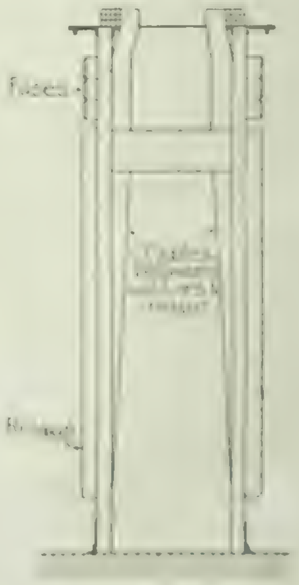


FIG. 20

Fig. 18.—Two pairs of bays.
Fig. 19.—Line of panels.
Fig. 20.—Bay of relays.

send 12 impulses per second; the brushes are driven over the idle trunks for trunk-seeking at 20 per second. The final switches, for the reason that the selection of the wanted line may be performed over long junctions, is driven at a slightly lower speed, namely 20 r.p.m., and eight impulses per second for the trip spindle and 14 lines per second for the line selection. It will be apparent that since the selection by the switch is controlled by means of the impulses which the switch delivers to the distant quick-acting controlling mechanism, the speed of any bay of switches may be reduced to any desired extent by the expedient of supplying proper gears and so may be given ample margin for operation over trunks of high resistance or of great capacity, or any other conditions which make the operation at maximum speed difficult.

The bay of selectors carries a group of 11; but the traffic in the exchange here in view is such that the bay ordinarily requires equipment of only 10 machines. For groups of subscribers' lines which receive relatively few calls, a single bay of final switches suffices; for those that receive heavier traffic, two or more bays are multipled together at the upper terminal blocks and may be equipped with any number of brush frames—movable terminals—required within the capacity of the bays.

In the case of the second line finders and of the trunk group switches, a large number of bays are multipled together, dependent upon the amount of traffic which the entire group of switches is called upon to serve. Since the traffic into different groups of lines is different, the numbers of multiples required likewise vary; and similarly, as for example in the rows of the first group switches which pass a relatively light traffic to special operators' positions, the multiple in the particular rows of terminals leading to these desks may be extended throughout the entire number of switches. The trunk groups are graded —that is, the terminals occurring in the first part of the row are multipled fewer times than those further along in the row, in order that smaller trunk groups may be conveniently accessible, while the less accessible trunks, which are tested later and are less frequently taken up by any given machine, are more extensively multipled. The multiple is also "slipped" or connected in rotation to equalize the traffic amongst different switches. The transpositions to prevent cross-talk, the grading and slipping of the multiple are provided for in the horizontal cables at the tops of the bays.

The main and intermediate distributing frames, line and cut-off relays and service meters are much like those used in manual central-battery equipments—the difference being in details of winding in the relays and meters and of terminals on the frames. The cabling is, however, somewhat different. The line finders are cabled from the intermediate distributing frames in order that the incoming traffic may be distributed amongst the bays of line finders as required, for equalizing the volume of traffic and adjusting it to the capacity of the groups of finders, or for bringing the incoming calls to particular operators' positions, or special groups of mechanism. The final switches are cabled to the main distributing frame. Since the numerical order of the lines in the final switches must be preserved, the traffic cannot be distributed amongst these switches, and the number of machines serving each group of 200 lines must be roughly adjusted to the traffic in the group. All cables are carried overhead in suspended cable supports, and so far as possible are carried centrally over the switch frames, separating into groups of horizontal cables, passing to right and left over the panels and dropping down to the particular bays. Cables run also from the sequence switches and brush terminals of the machine switches, which pass vertically up the bays, horizontally along the channels at the tops of the bays, and are gathered into groups which run to the multipled terminals in the adjacent switch racks.

The operating current for the controlling magnets and for the telephonic transmission system is taken from a storage battery of 25 cells. The battery is charged from either of two charging motor-generator sets, of which the charging side delivers current at 69 volts, while the motor side takes current at 220 volts. Provision is made for keeping the working voltage of the battery between 44 and 52 volts. Ringing current is supplied from ringing dynamotors driven from the power-supply mains. The driving motors for the machine switches are ordinarily directly connected with the supply mains of 220 volts. There is a reserve set which upon failure of the supply mains is automatically put into action, taking current on its motor side from the storage battery and delivering it at 220 volts to the switch motors. Thus any interruption of the main source of supply causes no interruption of operation in the exchange. The storage battery is capable of maintaining the entire load of the exchange for 48 hours. The power switchboard consists of marble panels carrying the switches and rheostat handles for controlling the charging and ringing motor-generators, switches for charging and discharging the batteries, regulating end cells, automatic overload circuit breakers, and an automatic switch operated upon the failure of current in the motor supply mains to put the reserve motor-generator into operation.

In an adjacent room are placed the operators' tables, 30 in number, and arranged in two rows. Twenty-six are equipped for operation. Each table accommodates one operator: 21 trunks are assigned to each position—to permit each operator to make and supervise connections in that number as a present maximum, with a capacity of 30. Each trunk is represented before the operator in four lamps, of which one indicates an arriving call, two are supervisory lamps, and one is a ringing signal.

The keyboard of each operator's position contains a group of press-button keys numbered with the digits—a strip of 10 keys (10 digits) for each numerical order in the system of subscribers' numbers, together with a key for each office name and special service, such as toll telegraph, information. These keys are constructed for easy operation, with a long stroke to avoid accidental operation, and with a magnet which holds fully depressed keys for a moment to prevent a too brief depression. For each position there are two groups of numerical registers, each of which is in fact a sequence switch, one for each order of digits and of offices. The motor magnet and contacts of the register are so connected with the corresponding digit keys that the pressure of any digit puts the corresponding register into motion, causing it to rotate until a circuit is closed between the depressed key and a particular set of switch springs of the register occupying the numbered position corresponding to the depressed [illegible] the [illegible] so preventing a [illegible] of the depressed key. Immediately after the registers take the positions indicated by the keys the magnets holding the latter are de-energized, an idle register set is associated with the keys and the latter are restored to normal position in readiness for another call. The registers take position within a second. Each group of registers in the semi-automatic portion of the equipment is connected with a mechanism composed of relays which receives the reverting impulses from the selecting switches, counts them up to the number recorded on the register, and thereupon opens the circuit through the moving switch and stops the latter in the chosen position. The switch, as before explained, then seeks an idle trunk in the group, during which time the registers remain inert, giving ample time for searching over any number of trunks or for repeatedly testing the same trunks. When the idle trunk is found and taken the next order of registers is put into action and chooses the succeeding group of trunks. Since the final switch contains two groups of 100 lines each, the preceding group selector chooses one of 10 groups of trunks each leading to 200 lines and collectively to 2,000, and the switch preceding that chooses one of 10 groups of 2,000 lines to the total [illegible]. The register for the units has [illegible] positions and the counting relays for the units are 20 in number; the register of 100's, according to whether it is set to the even or the odd hundred, either causes the breaking of the circuit controlling the switch motor at the desired unit digit during the first 10 impulses returned by the final switch (if the required number falls in the first vertical half of the terminal field) or withholds the operation during the passage of the switch over the first half of the arc and produces the same result when passing over the digit in the second half of the arc, in case the second hundred of the group contains the required number. This arrangement is known as the "counting" system.

The operator has for each cord a listening key with which she may connect the telephone into the cord or junction circuit as in manual practice, a metering key which operates the subscriber's message register, and at the same time brings about disconnection, a common key for holding a selection in progress, a common key for ringing the calling party, and a key for holding a faulty junction. Each three adjacent operators' tables comprise junctions leading to second line finders so distributed over the arcs containing the terminals of the first line finders as to give access to the three tables from all lines in the exchange up to 10,000. The 21 junctions in one table lead to second line finders so distributed as to give access to the particular table, under the initial conditions, from 2,700 subscribers. Thus any one of 2,700 subscribers can originate a call [illegible] to a particular operator; all the subscribers in the office (initially 7,000) can originate calls which through a limited number of [illegible] of three adjacent positions. For the incoming calls the operating team is 10, the [illegible] distribution amongst the operators [illegible] can be passed to any one of [illegible]. If a number of [illegible] the choice of the particular operator is [illegible]. Dealing with calls [illegible] the [illegible] of load arising from such [illegible] distribution are slight in comparison with inequalities in the work and in the handling time resulting from other causes, and they are compensated for by the certain means to be described a little later.

The ability of second line finders connected with an operator's table to search for and take arriving calls is determined by opening or closing the test circuits of the second line finders terminating the trunks leading to a particular position. When the operator is absent from her position and her telephone plug is withdrawn from the position jack the test circuits of the line finders leading to the position are open and the finders do not take calls. Similarly when the operator is engaged in answering a call or in telephonically supervising a trunk circuit the test relays are disabled and idle trunks leading through the position do not search for calls, excepting under certain special conditions.

It will be apparent that though provision is made for distribution of calls amongst the positions of the team, rushes of calls will nevertheless occur which will exceed the capacity of the team of operators at the positions. The calls in excess of those which can be distributed one by one to all positions occupied but not busy of the team, nevertheless, are permitted to pass to occupied positions—even though these may be busy at the moment—where they are indicated by the calling lamps and thus signify to the operators and to the monitors the necessity for speeding up work to take care of the momentary rush or, in case some positions are vacant, for adding operators. In order that the excess calls so passed to positions may not be delayed unduly or kept waiting before an operator engaged on a troublesome call, two special features are employed known as "timed distribution" and "helping out" respectively.

The "timed distribution" consists in maintaining the busy test of the operator's position for a measured time after the passing of each call to her telephone, and increasing this measured time progressively for second and third calls passed to the position in quick succession. When a call is passed to an operator's position the position is made busy for three seconds, which period—together with the time required by the mechanism itself to seize and pass to the telephone another call—cover the average handling time for the call. After the arrival of a first call therefore immediately succeeding calls must pass to other positions. During normal loads some position usually will be idle to take the call. A call arriving while all positions are busy will be taken by a finder of some position, but in such a case the timing device will maintain the busy condition for five seconds instead of three; for that period directing other excess calls to other positions. Provision is made for the arrival of a third order of calls, though such calls are highly improbable. The busy periods can be adjusted.

The "helping-out" feature may be regarded as the equivalent to a certain extent for the arrangement in a manual multiple switchboard by which an operator reaches over and answers a call at a neighbouring operator's position. It consists in extending the circuits of the operator's position mechanism, such as telephone number keys and registers, to the adjacent positions at either side, under control of "helping-out" keys by which the arrangement can be thrown into or out of service at will, permitting an operator to take from an adjacent position one or more calls which are waiting instead of passing to the telephone at that position. Thus any operator momentarily free and observing an unattended call at either of her neighbours' positions may, by operating the helping-out key, take over the call, receive the order, and perform the numerical selection; or during periods when some positions are idle a monitor may by plugging into the telephone jack at an idle position take over a waiting call from a neighbouring position.

A limited number of lines, about 200 initially, are arranged for trying "full-automatic operation," the subscriber's station being equipped with a dial-number transmitter. These full automatic lines are multipled upon first line finders, which are in turn represented in special second line finders and trunk circuits which differ in certain particulars from those appearing before operators and adapted for semi-automatic operation. The registers, generally, of the same form as those of the operator's equipment, are arranged to be set step-by-step by impulses from the subscriber's dial; they are not associated with counting relays, but are themselves moved around step-by-step by the impulses returned by the selecting switches to the zero position at which the selection is completed. The number chosen by the register is thus the complement of that sent by the subscriber. It will be unnecessary to describe in detail the manner of operating the full automatic equipment further since reference may be made to a description* of the full automatic exchange operated by the British Post Office at Dudley. The trunk circuits in which the second line finders terminate are of the same character and have the same mode of operation as those provided for the operators, excepting that those circuit arrangements and appliances are omitted which serve for passing the call to the operator, for displaying the signals before the operator, and for releasing the connection by the operator. The release is brought about by the replacement of the receiver at the calling station, a simple alteration in the circuit being arranged for permitting the conversion of any of the trunk circuits at the operator's position for automatic release by the subscriber if desired. The trunk circuits operated by the subscriber's dial perform selections and other operations through the same machine switches which serve the operator's trunk circuits.

TOLL TRUNK.

The office in question is the centre of an important toll traffic which is provided for in the usual manual toll and recording positions. The switching of calls from lines demanding toll connections and of calls for lines of the automatic equipment are performed by machine switches. A call originating for a toll line is disposed of by the operator by pressing a special toll key which directs the call at the first group selector into a group of trunks leading to a recording position, where the recording operator notes the numbers of the called and of the calling parties; or by the operation of the dial by the full automatic subscriber which sets the register to a special position and so directs the call to the same group of trunks to recording operators. Provision is made for the automatic prevention of metering calls to the recording operator.

The toll operator upon obtaining the required toll connection establishes connections with the subscriber's line through the machine-switching apparatus. Each of the toll positions—20 in number—is furnished with numerical keys like those of the semi-automatic operator, connected however with a single set of registering relays. One hundred toll switching trunks are furnished, which appear multipled in the toll positions in jacks and busy lamps. The manual cord circuit is of the "universal" variety and is used by the operator for establishing "through" connections as well as for toll-to-local connections. When an operator requiring connection with a local subscriber inserts the plug into the jack of a free toll-switching trunk, the group of number-selecting keys is automatically associated with the trunk taken. Each trunk ends in a first group selector of somewhat special character. For the purpose of avoiding connection of the toll-switching group selector with the general multiple cabling of the first group selectors, the toll selectors are multipled amongst themselves only, and are arranged for the performance of two numerical selections and a trunk-seeking operation in the same selector, thus dispensing with the second group selector. The choice of the brush group for the required row of trunks is performed by the trip spindle as described. The outgoing trunks terminating in each row are divided into several groups of three and four each; the switch chooses the required numerical group in the row, and then tests over the trunks in the group for a free trunk. The trunks in each small group lead directly to final switches which are of special character for the special functions of toll switching, but which are also available for local switching. The toll switching final selectors are multipled upon the second group switches accessible to the semi-automatic operators, but are placed last in the second group switches in order that they may be less frequently taken up for local service. The sequence switches of the final toll switches are set to special positions when selected by toll switching trunks, in which they provide certain facilities for the toll operator. In case the local line tested is free the initial period of ringing current is applied by the sequence switch, after which the sequence switch advances further to a position permitting the toll operator to ring again if required. The supervisory lamp of the operator's cord circuit is placed under the control of the called party, permitting the toll operator to follow the progress of the connection.

In certain other plants of the same type the special positions assumed by the sequence switch when the final selector is taken by a toll switch do not apply the ringing current immediately, but provide for listening upon and if desired breaking an existing local conversation and taking the line wanted.

When the same final selector is appropriated by a second group selector in the progress of an ordinary local connection the sequence switch is automatically driven over the special positions and the switch operates like the ordinary final selector.

TRAFFIC BETWEEN MANUAL AND MACHINE-SWITCHING SYSTEMS.

The particular exchange equipment above described is in the single large office of the area; conversion of the area to automatic working takes place completely with [illegible]. When the [illegible] long [illegible] of a [illegible] area, special [illegible] is required for passing calls from the manual to the automatic equipment, and from the automatic to manual equipments, without impairing the telephonic service or reducing the efficiency of operation of the automatic equipment.

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* B. O. Anson: "Western Electric Company's Automatic System." Paper read before the Institution of Post Office Electrical Engineers, 4 December, 1916.

For receiving traffic from a manual office to lines in a machine-switching equipment, semi-automatic positions are furnished in which the junctions terminate from the manual office. These junctions may as desired be on the ring-down or the order-wire basis. If operated on a ring-down basis, as will be found suitable for a number of small groups of trunks with light traffic from small offices, the trunks are connected with relays controlling the calling lamps in the operator's desk. If the traffic be very light and the trunks numerous, it is desirable to collect the traffic from a considerable number of junctions in a relatively few circuits in the position by means of second line finders, as though the ring-down junctions were calling subscribers' lines. In the case of large groups of trunks efficiently used, the order-wire method of passing the call is desirable and conforms in a large number of cases with existing arrangements in the manual boards. In this case the manual junctions are led into the operator's position and are connected permanently each with a first group selector. The operator's keyboard contains keys (termed "assignment keys") one for each junction, which when operated brings about the connection of the operator's registers and number-keys with the particular junction. The operator upon receiving an order for a wanted party in the automatic office selects an idle junction in her position, designates it by number to the ordering operator (who plugs into it at the outgoing end) and depresses the keys of the number called for. The registers take the positions corresponding with the number ordered, release the numerical keys, and perform the mechanical selection of the wanted line. Supervision remains in the manual board as usual. Disconnection takes place automatically when the plug is withdrawn at the outgoing terminal of the junction in the manual board.

The service at the incoming semi-automatic terminal of the junction is surprisingly accurate and prompt; the calls are disposed of with such swiftness as to reduce the [illegible] of the "B" operator upon the "A" operator while permitting the carrying of a substantially increased load by the "B" operator.

Passing traffic from a machine-switching office (whether semi-automatic or full automatic) to a manual office is performed with the aid of a number indicating device before the incoming junction operator in the manual office, which reproduces before the operator visually the number stored in the registers by the semi-automatic operator or by the subscriber. The switching apparatus performs its selections within the machine-switching office quite in the ordinary manner, and in due course selects an idle junction to the manual office; the taking of the [illegible] lamp to light [illegible] with the terminal plug of the junction at the manual office and [illegible] registers [illegible] order represented in the number to be indicated. These registers operate consecutively, delivering impulses of current to the primary registers in the machine-switching office precisely as trip spindles would in selecting brushes. The secondary registers of the call indicator are thus set to positions corresponding to the numbers first stored in the registers. The action of the non-decimal translating mechanism is suspended, the number recorded in the call-indicator register being the decimal. Before each "B" operator is placed an indicating appliance composed of small lamps placed behind stencilled numbers beneath a ground-glass plate. When the indicator registers have taken position, combinations of circuits are closed which cause the lighting of the lamp beneath the figure to be indicated for each order of numerals, displaying the number plainly before the incoming junction operator; she thus observes simultaneously the identifying lamp of the junction carrying the call and the number wanted. Upon inserting the terminal plug into the jack of the wanted line the indication is effaced and the registers and indicator are freed to take other calls. This means of passing calls is substantially more accurate and prompt than the method of telephonic ordering commonly employed.

TELEPHONE SERVICE IN MACHINE-SWITCHING SYSTEMS

The benefits derivable from the substitution of machines for operators and manual-switching apparatus are of three principal sorts: improvements in service, economies, and freedom in development.

The user of the telephone is interested in the accuracy and promptness with which switching is performed and in the constant availability of his individual equipment, and he obtains, from machine switching, gains in these particulars which are definite and substantial. In manual switchboards, the errors in switching may range from a minimum of about 2·5 per cent to above 5 per cent, dependent on whether junction-working is involved. In machine-switching systems they may be brought readily to a daily average of ·1 per cent, and in certain equipments have ranged about 0·25 per cent and as low as 0·1 per cent. In semi-automatic operating, the operator easily attains the same skill in manipulating keys as in typing, and her errors become negligible. A mechanical equipment in good order will perform thousands of selections without error. Both sources of error are independent of junction working.

The promptness of switching in the full automatic system leaves little to be desired by the user. The ringing of the bell at the wanted station begins practically as soon as the calling party completes dialling the number. In systems with operators, the delay which ordinarily impresses the subscribers is that in reaching the operator to give his number, and the quality of service is judged by the percentage of occasional long delays, as well as by the average time of response. The standard for service in manual exchanges generally accepted has already been referred to—the average response for the number is 3·5 seconds after the subscriber takes the telephone with no more than 5 per cent delays exceeding [illegible].

The table shows the times for answers measured from taking the telephone (or calling) to the answering operator's response :

Answering times, average.

	Seconds
Manual central battery, standard ...	3·5
Manual central battery, heavy load, " M " ...	4·5
Semi-automatic system, " I " ...	2·1
Semi-automatic system, " J " ...	2·2

Percentages of answers in different times.

Seconds ...	1	2	3	4	5	6	7	8	10	Longest
Manual standard ...	—	—	—	—	—	—	—	—	95 %	—
Manual C.B., " M " ...	—	10 %	50 %	76 %	86 %	—	—	96 %	98 %	26 sec.
Semi-automatic, " I " ...	1 %	65 %	89 %	97 %	—	99 %	—	100 %	—	8 ,,
Semi-automatic, " J " ...	18 %	69 %	84 %	91 %	95 %	97 %	98 %	99·3 %	100 %	9·2 ,,

The time of operator's response is perhaps not the most significant measure of the efficiency of switching, notwithstanding the subscriber's proneness to form judgment on that basis. Another measure is the time from initiating the call to the beginning of ringing the bell at the wanted station. Within this period there is no delay which is not directly dependent upon the operator and the apparatus except the drag of the subscriber in giving his order, which ordinarily is not a large factor.

Time from initiating call to ringing bell of called station.

	Seconds (average)
Manual C.B. exchange, " M," best performance	10·3
Manual C.B. exchange " M," heavy load ...	12
Manual C.B. 100% junction calls	18·5
Semi-automatic, " I "	10·3
Semi-automatic, " J "	10·5
Full automatic, " H "	8·5

Data for direct comparison of the time of connecting for the same subscribers' lines by manual and by machine switches is at hand for only one office, I, located in France. The replaced equipment was a magneto board ; the replacing equipment a Western Electric semi-automatic machine system. The measured times run from the moment of the operator's answer—the insertion of the plug in the one case, the passing of the call to the telephone in the other—to the beginning of ringing. This data is presented in Fig. 21 in the form of two curves, showing the times required for completing different percentages of connections. In the machine equipment, the average time is about half that formerly experienced, and 95 per cent of the connections are made in one-fourth the former time, the maximum time being only one-fifth of the former maximum.

The shorter time noted in the above table for the full automatic system is due to the omission of the time waiting for the operator. Otherwise the time for getting connection in a self-contained office is not largely different in manual and in machine-switching systems. In multi-office

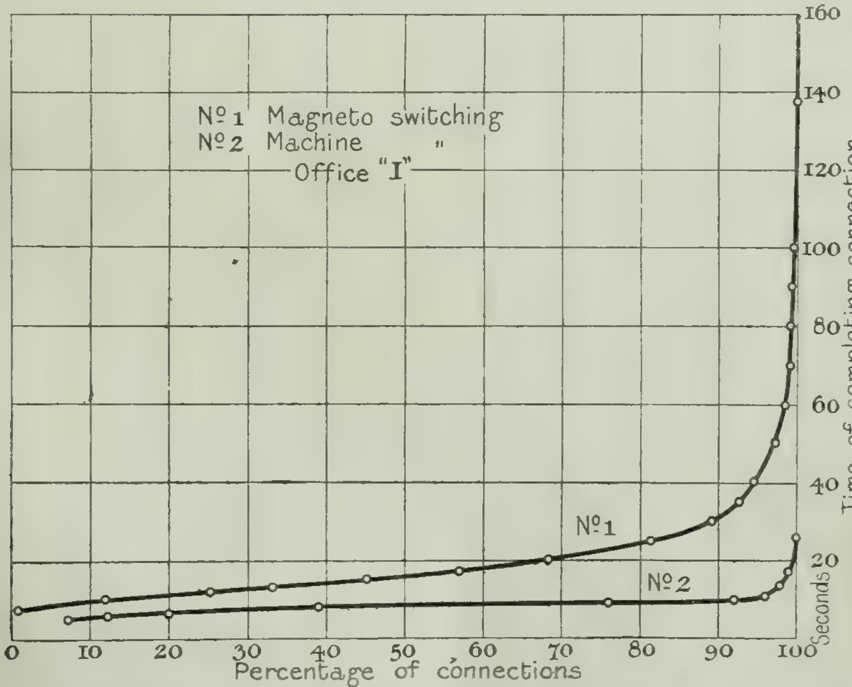

FIG. 21.—Time for making connection expressed in percentages of connections in different periods.

[illegible] calls, working through second operators adds largely to [illegible]

[illegible] ne-switching equipments is given for three offices in Table 7. The office S is one of the largest, most important, and best operated manual equipments.

[illegible]

Office	"S"	"J"	"I"
[illegible]			
[illegible] ...	[illegible]	700	[illegible]
Time to answer ...	[illegible] sec.	[illegible] sec.	[illegible] sec.
[illegible] average	[illegible]	[illegible]	—
" maximum	—	4·3 "	—
minimum	—	[illegible]	—
[illegible] ...	[illegible]	0	0
Connections to wrong lines	[illegible]	0	[illegible]
Double connections...	[illegible]	0	0
Total errors, local ...	[illegible]	0	[illegible]
[illegible]			
Calls observed ...	[illegible]	—	—
[illegible] ...	[illegible]	—	—
[illegible] lines	[illegible]	—	—
Double connections...	[illegible]	—	—
[illegible]	[illegible]		
Total for both "A" and "B" [illegible] ...	[illegible]	0	1
[illegible] ...	17·[illegible]	—	—
[illegible] ...	[illegible]	10·8	7 [illegible]
[illegible]	[illegible]	4	[illegible]
[illegible]	[illegible]	1·8 %	—
[illegible] party	[illegible]	8·5 sec.	10·4 sec.
Time from operator's answer to called party's answer—			
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	—	—
[illegible]	[illegible]	0	0
[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible] due to the accidental withdrawing of plugs; the percentage for office S is rather lower than normal. No corresponding interference takes place in the mechanical [illegible] plugging in or from defect in or failure to recognize the [illegible] have failed to produce double con- [illegible]

[illegible]

The item "Calls affected by poor maintenance" describes faulty connections, errors or failures due to causes traceable to mechanical defects in the switchboard. The office S is unusually well maintained; the corresponding percentage of error in the office M was 2 per cent.

The data covering the percentage of connections supervised must be explained. In offices S and I all connections are supervised with the telephone. The percentage given for office S covers calls supervised for disconnection, and includes attempts to recall, busy and "don't answer" calls, but not operator's errors. The percentage for office I covers all cases of supervision required for irregularities, including recalls, busy, don't answer, errors and subscribers' flashing for attention. Office J is operated under an instruction to supervise only when required; the percentage covers all cases of operator's and subscriber's errors and recall signals by the subscriber, together with failures to answer the ringing signal in a reasonable time and failure to give up the call on the busy signal within reasonable time. It may be correctly taken as indicating a high quality of service requiring little supervision.

A third improvement in service of marked value, but obscure origin, is that before referred to as an increase in the availability of the subscribers' lines. The duration of a connection is noticeably less in machine-switching systems.

[illegible] of connection.

	Seconds.
Manual magneto, accepted average	180
Manual magneto, office I	175
Manual, C.B., accepted average	120
Full automatic, Strowger	83
Full automatic, "H"	112
Semi-automatic, "I" calling line	102
" called line	97
Semi-automatic "J"	[illegible]

It is notable that at office I, where accurate observations were made of duration before and after the installation, the change brought the holding time down from 175 seconds to 102 seconds—or, if the occupied times of the pair of lines be taken, from a total of 332 seconds to 199 seconds, a reduction amounting to 40 per cent, and resulting in more than proportional increase in the availability of the line and decrease in the percentage of busy calls.

The more obvious economies offered by machine switching are in operating and supervising forces and in plant. The possible net savings in operating are still subjects of controversy, which, however, is in a fair way to settlement by reason of the increasing volume of reliable data; while the savings in plant which might be made are still somewhat speculative, no complete development plan having been carried out wholly on the most promising arrangements permitted by the use of machine switches and distant control.

The range of variation in wages, loads and relief forces [illegible] and depreciation of machines, is such that a judicious choice of factors permits a demonstration of either gain or loss in [illegible] and practical experience, however, the case seems to be made out with increasing margin for the machine switch.

The handling time of the operator per connection is a very significant though not an entirely satisfactory measure of probable operator's loads and costs of operating, for the reason that it is definitely measurable and comparable in different systems. The busy-hour load is, however, fairly indicated by dividing the seconds per hour by the average seconds of handling time per call; the discrepancies produced by that process are not so great in the case of semi-automatic as in manual switching. The two main influences which restrict the raising of loads in manual working—the increasing delay to the subscriber and the fatigue of the operator—are greatly reduced in automatic working. The calls passed to an operator in an hour by reason of their greater number are more evenly distributed through the time; the more prompt and equable distribution of the calls amongst the operators is permitted by the mechanism and by the prompt access to an operator; and finally, the period of handling is so short that delaying one, or even several, calls while the preceding one is being served imposes only a slight absolute delay.

Whereas in manual switching the long handling times made the restriction of the operator's load necessary in order to avoid excessive delay in answering the call, it will have been noted in Figs. 11 and 12 that in mechanical switching the operator may be loaded to her physical capacity without producing delays inconsistent with good service.

The other factor above mentioned—the fatigue of the operator—is very noticeably less in machine-switching systems. Accepted manual practice has favoured keeping an operator occupied about 60 per cent of the hour, with occasional short periods of 75 per cent. With such loads, the operator is physically and mentally busy. In semi-mechanical operating, an operator may be kept occupied normally 75 per cent or 80 per cent of the hour, with higher percentages on occasion, and with such loads is working easily.

Table 8 shows operating loads actually experienced in several exchanges, together with loads computed from the observed data.

The office M probably represents the best performance attained in a standard central-battery manual board; the data noted were obtained during a special test to ascertain the maximum operator's load and the effect of high loads upon promptness of service. The loads given are those obtained under the best conditions and for a short period, and probably could not be maintained indefinitely.

TABLE 8.

Loads on Operators.

Type	Junction Working %	Observed Handling Time (sec.)		Estimated Load			Observed Load		
		Connecting Only	Connecting Supervising	Occupied Time %	Day Load	Busy Hour Load	Busy Hour Aver.	Maximum Hour	Occupied Time %
Manual Switchboard—									
Standard	0	—	10·25	65	230	245	—	—	—
Standard	100	—	15·30	65	150	160	—	—	—
Office M	0	—	7·50	65	—	312	358	405	84
"Keyless" N	0	—	8·64	65	270	290	—	—	—
G.P.O.	0	7·20	11·50	65	—	200	—	—	—
G.P.O.	100	11·00	16·50	65	—	140	—	—	—
Call distribution "L"	0	5·90	—	—	—	—	347	—	57
Machine switching—									
Manual answering ...	0–100	—	6·36	70	—	400	358	—	—
Automatic answering...	0–100	—	—	—	—	—	—	—	—
Office F	—	6·21	—	75	400	435	400	600	—
,, O	—	5·00	—	75	—	500	400	550	—
,, P	50	4·70	—	75	—	570	540	—	—
,, Q	—	—	—	—	—	—	—	600	—
,, J...	—	3·60	3·70	75	—	726	—	550	56
,, I...	—	3·50	4·50	75	—	600	—	—	—
,, R	—	5·00	—	75	—	540	575	—	—
Incoming junction ...	—	3·00	—	75	—	900	600	900	—

The office N exemplifies the improvements resulting from eliminating as far as possible the operation of ringing and listening keys; the switching operations remain unchanged.

For the office L the work of the subscribers' operator only is given. In practice her work is supplemented by that of manual distributing operators who, though they increase the efficiency of the "A" operators, increase also the delay, the total handling time, and the expense per connection.

The automatic exchanges F, O, and P are of one type, and offices Q and R are of a somewhat different type; but they have in common the features that no supervision of connections is afforded, and that disconnection is automatically effected by the replacement of the telephone at the calling station; that the calling party can recall at any moment and obtain a different operator; and that the operator is very quickly connected through to the calling party and saves the subscriber's drag in obtaining the number after she has announced her readiness for it.

The exceptionally high handling time noted for office F appears to be partly, and perhaps largely, due to the fact that the operators are required to speak German, while a large proportion of the subscribers speak Polish.

The low handling times in the cases of offices I and J are partly due to a measured delay amounting to about two seconds imposed on the originated call before it is connected through to the operator's telephone, and to the automatic announcement by a momentary buzzing tone of the operator's readiness for the number just prior to the connection. Thus the subscriber's drag is to a large extent eliminated, with a resulting saving in the operator's time. Note also that the subscriber gives and the operator repeats only four digits.

While the foregoing table affords scope for much definition and qualification, and illustrates the complicated and somewhat unsatisfactory nature of comparisons of operator's loads, a few significant facts are salient. An operator at a manual central-battery board with no trunking can give fairly prompt service without undue fatigue under a load of 230 calls per busy hour, and can carry a load of 400 calls with exceptional fatigue and a notable impairment of service. Such an operator can give more prompt service with ease through a mechanical switching system under a load of 450 or more busy hour calls of like average character, and can carry [illegible] in exceptional cases without noticeable impairment of service or troublesome fatigue. Junction calls reduce the load materially in manual systems, but not at all in mechanical switching.

MAINTENANCE OF MACHINE SWITCHES.

As in the earlier history of the conversion of central office equipment from the magneto to the central-battery system, [illegible] switching systems, the difficulties and expenditures actually experienced [illegible] the results of progressive [illegible] and in practice. The early automatic exchanges required the attention of men in such [illegible] skill to keep the equipments in good [illegible] der that their wages largely or quite counter[illegible]e savings in operators. Experience with modern [illegible] required for manual equipments of equal size; while the faults re[illegible] staff.

The expenditure in wages constitutes the main item of maintenance expenditure; those for materials and replacing parts are practically negligible.

The labour of maintaining certain typical automatic exchanges is shown in Table 9, expressed in man-hours per line per year.

These examples have been selected as typical from amongst a considerable number because of the fairly accurate and complete data available with respect to them.

The year is estimated at 313 days to bring all examples to equality with certain equipments in which there is no maintenance on Sunday—excepting in the case of office H, calculated for 12 months from data of one month. The number of lines given is that of lines actually in operation. In all cases except offices G, H, and I, the numbers of man-hours cover the time of maintaining the switches only, excluding time spent on power plant, distributing frames, and manual switchboards. The times given for exchanges G and I include the maintenance of the power plant and manual portions of the equipment, while that given for office H includes the work on manual toll switchboards but not on power plants.

The errors noted for exchanges A, C, D, E, and G were observed by standard service tests from substations; those for offices H, I, J, and K were observed by tests and observation at the main distributing frame.

Offices A to F inclusive are ratchet-driven equipments, while offices G to K inclusive are power-driven.

Offices A, B, C, G, and K were operated by telephone companies, while offices D, E, F, H, I, and J are operated by Postal Administrations.

In offices of relatively small size the amount and cost of labour is largely affected by the need or preference for continuous attendance. Offices A to F, and K, are attended continuously through 24 hours, offices A, B, C, and K by men in three shifts, offices D, E, and F by men in two shifts. Office G was operated for 12 hours per day only, with continuous attendance during that time; office I operates and is attended from 7 a.m. to 12 p.m.; office H operates through the 24-hour period, attended only from [illegible]; office J operates throughout 24 hours with attendance during 12 hours.

A special study was made at office G to determine the effect of reducing the hours of attendance. For a period of 11 days, during which 83,000 connections were recorded, all maintenance of the equipment was withheld, with the [illegible] to put it out of operation. The equipment gave satisfactory service throughout the period. For an equal number of

TABLE 9.

Maintenance Labour.

Exchange	A	B	C	D	E	F	G	H	I	J	K
In service	1907	1910	1910	1910	1911	1912	1909	1914	1915	1915	1915
Type	Full	Full	Full	Full	Full	Semi	Semi	Full	Semi	Semi	Semi
Lines	11,500	2,000	5,000	750	2,300	3,150	450	700	900	780	6,500
Call-rate	—	4·5	4·5	3	10	12	22	—	2	10	3
Errors %	5·4	—	5	17	5·3	—	0·25	—	—	0·01	0·37
Man-hours per line per year ...	6·7	6·3	3·2	12·6	11·5	5·4	6·6	6·1	5·5	2	5·2

connections just prior to the test the percentage of errors (failures to obtain proper connections) was 0·27 per cent; at the end of the test the percentage of error had risen to 0·57 per cent. In a later test the maintenance and repair of the equipment was suspended for a period of six weeks; attention was confined to recording the errors and removing the fuses from switches marked as frequently producing errors. During this test the percentage of error did not change substantially, but at the end of the period of six weeks 12 per cent of the selectors had been temporarily withdrawn from operation for cleaning or repair. The switching service was satisfactory throughout.

TABLE 10.

Analysis of Recorded Faults. Machine-switching Equipment.

	G	H	I	J	Total
Lines equipped ...	450	800	1,400	1,200	3,850
Lines connected ...	400	630	750	780	2,560
Machine switches ...	311	378	285	314	—
Calls originated ...	370 M	700 M	400 M	1,500 M	2,970 M
Days reported ...	49*	259†	259†	259†	—
Without faults ...	—	100	153	120	—
Faults reported ...	—	244	124	206	—
Faults cleared ...	105	221	98	170	593
Analysis of Faults.					
Definite defects ...	25	37	26	42	
A part replaced ...	10	9	8	6	
A loose part fixed	—	21	3	5	
A repair to wiring	15	7	15	31	
Doubtful repairs ...	80	186	67	148	
A part adjusted ...	15	113	48	11	
A clutch cleaned	1	34	1	20	
A contact cleaned	64	39	18	117	
Faults per 100 M Calls.					Average
Faults cleared ...	28	34	24	11	20
Definite defects ...	7	5	6	3	4·3
A part replaced ...	2·7	1·3	1·1	0·4	1·1
A loose part fixed	—	3	0·9	0·4	1·0
A repair to wiring	4	1	4	2	2·3
Doubtful repairs ...	21	29	18	8	16·0
A part adjusted ...	4	16	12	0·7	6·0
A part cleaned ...	0·2	5	0·2	1·3	2·0
A contact cleaned	17	6	4·5	7	7·9
Faults in Machines.					
Sequence Switches—					
A part repaired ...	2	2	1	4	
A part adjusted ...	15	77	4	5	
A part cleaned ...	39	86	11	69	
Switches and Finders—					
A part repaired ...	12	0	3	1	
A part adjusted ...	0	14	17	5	
A part cleaned ...	1	8	3	2	
Band cable	0	2	3	7	

* November 1 to December 31, 1913.
† January 15 to September, 30, 1916.

These instances indicate that with apparatus of good construction the quantity of labour can be largely reduced by withdrawing attendance during slack hours, nights, and Sundays.

A minimum attendance probably can be reached by employing one man in a single shift of eight hours during the busy portion of the day. For a 1,000-line exchange this would result in 2·5 man-hours per line per year. Studies made in exchanges G to K indicate that the time of the attendant would be occupied to only a very small extent in inspecting, testing, and repairing the switching machines. For example, in exchange G the average time for discovering and correcting a fault or defect was three minutes; and all such work occupied about one hour per day. A study in exchange J shows for a month a total of 6·5 hours in discovering and eliminating faults (averaging 12 minutes for each case), 19·5 hours for routine testing, 45 hours for inspection, and 57 hours for cleaning. The extent to which the spare time of the attendant can be utilized for maintaining the power plant, distributing frames, and manual equipments has not been determined.

Corresponding records are at hand of the faults discovered in the four power-driven machine-switching systems G, H, I, and J, of which three are semi-automatic and one is full automatic. A tabulated analysis of faults reported, identified, and corrected is shown in Table 10.

A division of the "faults cleared" into two classes will be observed, named respectively "definite defects" and "doubtful repairs." Definite defects include faults of an unmistakable nature; doubtful repairs include all the rest, being those of an elusive or transitory nature calling upon the mechanic for quick and careful observation, judgment, or reasoning. In recording faults of the latter class, errors of judgment are common and the responsibility of the mechanic largely affects the record. In the absence of a definite indication of the nature of the fault, one attendant will do nothing, while another will perform and record some more or less innocuous repair; one will attribute the same failure to dust, another to some irregularity of the clutches or contacts.

The mechanical switching equipment is composed of the machines before described, together with a large number of relays and a large amount of cabling; under the caption "faults in machines" the classes of defects and faults which occurred in the moving machinery alone of the system are exhibited.

Questions will occur as to the performance of characteristic features of the machine-switching equipment here described. Among these the most significant is perhaps the security of the talking circuit produced at the contacts of the selectors and finders. No case has been reported from the exchanges H, I, and J of a failure to make a perfect circuit on the finder or selector—that is no failure has been observed of contact between the bronze collector springs and commutator rings, leaf springs and brushes, or brushes and terminals. The line terminals and brushes require no cleaning or attention.

The woven ribbon cable for the multiple connection at the rear of the arcs in the exchanges collectively has [illegible] or repairs, the cases being broken wires and loose bits of solder.

The driving power has caused practically no trouble. The number of cases in which attention was required by the motor parts ([illegible] and shafting of the selectors and [illegible]) at the three exchanges H, I, and J (2,230 lines) for the period of nine months is 25. Only one interruption of service due to a defect in the power apparatus has occurred, namely in exchange I, in which the field winding of a spare motor failed for 20 minutes because of moisture in a winding immediately after its installation for trial.

On the days reported "without faults," no faults or defects in operation were discovered by the maintenance staff or reported by users and operators. In the exchange I no subscribers' complaints of any kind were received for a period of six weeks, and for several periods of a week or more no faults have been observed in the mechanical switching equipment.

In the class of "definite defects" the item "parts replaced" (numbering 23 for all exchanges during nine months) cover broken springs and rubber bushings. The total value of parts replaced in all these exchanges is well within £5.

The item "loose parts fixed" comprises mainly screws set up.

The item "wiring repaired" covers defects in windings, wires, cables, and soldered connections.

In the class of "doubtful repairs," the item "adjustments" comprises the alteration of spring tensions in relays, selectors, and sequence switches, and changing position of clutch plates. "Cleaning clutches" covers mainly removing oil or grease resulting from handling; "cleaning contacts" covers the removal of dust and putting burned contacts in order. The considerable number of contacts requiring cleaning at exchange J is due to the current work of installing a substantial addition to the operating equipment.

The difficulty of obtaining men of sufficient skill and training for maintaining an automatic equipment often has been unduly emphasized. No doubt upon first examination a machine-switching system produces the impression of being complex beyond the grasp of many minds; these complexities, however, are readily resolved by a moderate amount of steady and continuous thinking into quite simple mechanical operations which make an unusual demand on the mind only in respect to the number of [illegible] parts and of operations in sequence. An assumption has been made in some cases that an automatic switching equipment could be maintained properly only by a mechanic trained at the shop in the manufacture and assembling of the apparatus, which, however, is believed to be true no more than in the case of a manual central-battery equipment. The exchanges A to C, G, and K have been maintained in the main by men trained in the factories and in the installation of the equipment; those in charge of exchanges F, H, I, and J, and a certain number of the other employees, have been taken from the Administration's forces ordinarily employed in the maintenance of manual central-battery equipments, starting with [illegible] and with a certain amount of instruction and experience during the period of installation and initial operation of the plant under the supervision of the installing engineer.

The foregoing studies distinctly indicate that a machine-switching equipment of either of the available types, of modern construction and of moderate or large size, can be kept in good operating condition with an expenditure of labour not exceeding 5 or 6 man-hours per line per year, and that the expectation may be entertained of reducing the labour in fairly large equipments to one-half that amount or less. Such a high quality of mechanical performance has already been reached that the number of man-hours per line per year is determined by the necessity or desire to have men present in the exchange during a part or all of the day, rather than upon the amount of skilled repair or interference in the equipment.

DEPRECIATION OF MACHINE-SWITCHING APPARATUS.

The actual depreciation—wear, breakage, and deterioration—in a machine-switching equipment is not heavy, and eventually may be found to be less even for the present types than the rate of depreciation commonly assumed for manual equipments. In the case of machine-switching equipments of the type here described at length, rather more than one-half of the value of the plant (as an average of 60 offices) consists of the apparatus familiar in manual equipments—distributing frames, meters, cabling, relays, and power plant; the remainder consists of automatic switching machinery, and power apparatus for it. The customary rate of depreciation would naturally be applied for the sorts of apparatus well known in manual practice. As to the switching machinery sufficient experience has accrued to warrant the expectation of a rate of actual deterioration in no case greater but possibly less. The exchange A, though of an early and somewhat imperfect form of ratchet-driven switch, is still giving satisfactory service. Office G of the motor-driven type above described, after operating six years was examined in detail with great care. The motors and clutches showed wear so slight as to warrant the expectation of useful life several times its period of service. The bronze terminals and brushes showed little more than glazed markings upon their surfaces, and were deemed suitable for 50 years' life. The sequence switches showed very slight wear. A few pivots exhibited wear, while about 100 of the small interrupter levers had required replacement. On the whole it would appear that the replacement or improvement of the interrupter levers would put the equipment in condition for certainly six, and perhaps 12, years of further service.

As already noted, the expenditure for replacing parts in four machine-switching equipments during nine months fell within £5.

Although exact comparative data are not available it would appear that the repairs in machine-switching systems will be fewer and less expensive than the repairs to cords alone in manual equipments.

In view of these facts it is the opinion of the author that an actual rate of deterioration for a machine-switching equipment may be assumed conservatively to be equal to that of a manual central-battery equipment.

An element which is important in estimating depreciation, or a factor in fixing of annual charges, is the probability of displacement by improved apparatus. This is always a difficult factor to evaluate, but in the present circumstances a portion of machine switching might find warrant for assigning to it a larger value for manual than for automatic switches.

Four principal causes for the displacement of existing equipment will be recognized: Failure in operation; unsatisfactory service; high operating costs; lack of adaptability to important changes in size of plant or in method. Testing the machine-switching equipment by these reasons for possible displacement, it would seem that definite failure to operate may be dismissed. The percentage of failures in switching as noted in the foregoing pages is in a number of existing equipments so small as to leave little incentive for the replacement of an equipment on the score of accuracy only. In respect to the time of switching, it is conceivable that mechanism may be produced which will connect the calling to the called line within two or three seconds instead of as at present in eight or 10 seconds. As the period occupied by the calling subscriber to perform his mental and physical acts of calling, and the time for the called party to respond to the ringing of the bell are not likely to be changed, the total time of getting a connection might be reduced thus by not more than one-fourth. Though such a difference in time of effecting connection might be adequate reason for initially choosing an improved type, it is doubtful that it would bring about actual displacement of an equipment in use.

The cost of maintenance tends towards a certain irreducible minimum. It appears highly improbable that any mechanical system of large value, situated as the majority of switching offices are in relatively isolated places, will be left without any attention. If a single skilled attendant be present during eight hours of the day for 300 working days per year there will result an expenditure of 2·4 hours per line per year for a 1,000-line equipment, or one-tenth that amount for a 10,000-line equipment. The reduction from the figure now easily attained of five hours per line per year to one-half that amount would effect a saving in wages of perhaps £120 per year. Displacement of an otherwise serviceable equipment in order to save one-half, or even the whole, of the maintenance charges at the present rate would not seem probable.

The consideration of the possible displacement by reason of substantial changes in the nature of telephonic service is of a much more speculative nature. The mere increase in number or change in distribution of lines, which have so frequently caused the displacement of manual equipments, do not affect machine-switching equipments to the same degree; in this respect they prove more elastic and adaptable than manual switches.

The observable tendency to a greater sub-division of exchanges into small offices or groups of lines scattered through rural and village districts, or in the form of private branch exchanges in cities, and in the city areas for the purpose of reducing the cost of underground plant, is in itself realizable in a high degree only with the aid of mechanical switching apparatus. Improvement is to be expected in telephonic transmission, possibly with the aid of telephonic amplifiers. Such an advance is in no way inconsistent with existing mechanical switching systems. Improvements in machine-switching gear are possible as noted in speed of connection and in the more efficient use of the common elements; such improvements probably would tend to increase rather than diminish the complexity of present systems by reason of the increased specialization of organs, as has been common heretofore in the development of the telephone industry. Such complexities are, however, in general in the nature of fixed circuit connections rather than in moving mechanism. The standardization of apparatus and methods commonly tends in the direction of early displacement of obsolescent types; but probably will not take place in machine-switching gear in any general way for some years. The comparatively simple central-battery switchboard required about 10 years for the development of the type to a point at which standardization became desirable and standard methods and apparatus suitable for it were available.

DISCUSSION BEFORE THE INSTITUTION, 22 MARCH, 1917.

Mr. F. GILL: I confine my remarks to two points, but first ask several questions. In Table 7 the author gives 1 per cent of errors under "I." Two hundred tests were made, and 1 per cent means that two calls went wrong. That does not seem to me sufficient to be characteristic; it seems rather like an accidental occurrence. It is a very important point, because if one were to take that as characteristic of the machine and multiply it into a 10,000- or 50,000- or 100,000-line exchange, the number obtained would be very large. In "J" in Table 7 the errors are given as zero, and in Table 9 as 0·01 per cent. The difference perhaps arises from the fact that the figures relate to two different sets of tests, which would be quite understandable. Then passing to Tables 9 and 10, are the errors eliminated by routine tests shown here, or are they simply eliminated and ignored in the figures? In connection with Table 9 can the author give us any information in regard to subscribers' irregularities? They are very important in manual work, and also regarding subscribers' dialing. Then in Table 10, do the calling rates and the switches installed correspond? It may be that the equipments have been designed with different chances of delay. Can the author give figures similar to that in Table 7, but relating to information calls coming in from fully automatic lines? If we investigate the figures of company-owned and administration-owned plant we find that those owned by administrations take about 62 per cent more labour to maintain than the others. An important point on which I wish to speak is the question of lost and delayed calls. In the paper a lost call is treated as a delayed call, but one can tolerate a much greater percentage of error if the call is only delayed, say, by the switch hunting for an idle trunk than if the call is actually lost. If a call is lost, the ordinary rule is that the subscriber gets an indication, which he interprets as "busy," but he does not know whether it is the trunk that is busy or the subscriber; he has to guess. In Table 6 three formulæ are given. One is taken from the Post Office Chart; the second I believe is due to Campbell, and the third is that of the Western Electric Company. There is a great difference in the number of machines which have to be provided, whichever formula is adopted. If one goes to too high a probability of Mr. Gill.

Mr. [illegible] [illegible] cost in the plant. After [illegible] conduct the service [illegible] give a reasonable service at a reasonable cost, with a reasonable profit. Therefore it is very important that we should not overshoot the mark and put in too many switches. As the author points out, it is very desirable to agree, at any rate for computation, for the balancing of estimates and records, upon what might be called a sea-level. I think, however, that the percentage of calls lost or delayed is not the ultimate basis. Supposing that two different switches have, let us say, 1 per cent lost or delayed calls; it may make a great deal of difference whether it is 1 per cent delay for one second or 1 per cent delay for 10 seconds. Therefore I think that what has to be aimed at is the total delay in seconds. Will the author give his views on a proposition in which one specifies for a delay not greater than 100 seconds in 100 calls, the maximum delay in any case not to exceed 20 seconds? Again, the author refers to the question of first cost. That is really the only point on which we disagree. He realizes that first cost is important and that it must be taken into account, but he does not really assist us on that question. Then I should like to know whether any of the cases quoted in the paper have been put in on the basis of economic selection. Have they been put in as deliberately paying an increased cost for an improved service, or have they been put in without any real economic selection at all, merely, on the basis that it was the latest thing to do because it got rid of the operator? As to how much the first cost of the automatic gear must be reduced to make it available for economic installation, the figures I have for a particular case show that if we take the manual first cost at 100, then the automatic first cost must be something like 140 or 145.

Mr. Mr. E. A. Laidlaw: I think that special attention is warranted in future studies to the increasing annual cost on operators' wages, as now, owing to the War, women having found a much wider field of operation for their labour, it can reasonably be expected that the expenditure under this heading is likely to increase considerably. The question of size of switch, and whether step-by-step or motor-driven, is one mainly of cost and flexibility; a larger switch than 100 lines appeals at first sight to every telephone engineer who has been engaged on traffic. This fact is brought about by the knowledge that the larger a group of junctions, the greater is the efficiency that can be obtained per junction. This, however, only applies to a limited degree on machine-switching equipments, as all originating calls incoming to the exchange can be brought through a standard intermediate distributing frame and first and second pre-electors or line finders, so that a switch for 100 lines can be made to give as good a service as a 200-line switch. An arrangement of this kind gives an [illegible] out of 100 junctions over which the traffic is equally distributed; therefore, the fluctuations in the traffic correspond [illegible], which, as is well known, are proportionately much smaller than in a group of 10 lines. The fluctuations in the traffic on a group of [illegible] not warranted from a [illegible] arranged [illegible] obtained, and the number of connectors to be fitted must be what is required for that particular 100 or 200 subscribers. However well the subscribers at the opening of the exchange are distributed to give equal calling rate on the hundreds, it is only a matter of time when alterations—either a decrease or increase in the percentage of connectors—will have to be made. This at present is not a serious difficulty, as extra banks of contacts (the cheapest part of the switch) can be provided at the initial equipment and the mechanism fitted, if necessary, at a later date. The advantage of a 100-line switch over the 200-line switch (although I think it is agreed that the number 100 was not scientifically determined but was fixed because of the decimal system) appears to be that it retains the decimal system without any translating devices and is very flexible, thereby having the advantage over the 500- or 200-line switch on small and medium sized exchanges. Taking the United Kingdom, for example, out of a total of about 3,100 exchanges the sizes range somewhat as follows:— Mr. Laidla

2,800	under	300	lines
[illegible]	..	[illegible]	
[illegible]	..	[illegible]	
100	over	1,000	,,

For exchanges up to 1,000 lines step-by-step mechanism appears to be preferable to motor-driven from a cost point of view. For exchanges above this, all calculations that I have been able to make appear to show that the first costs of step-by-step or motor-driven mechanism are abôut equal; and from an annual cost point of view the author's figures show that even with an old exchange fitted with the step-by-step mechanism which has not the latest improvements there is little difference in the cost of maintenance. A method of obtaining the minimum amount of switching apparatus is shown in Fig. A. This system is known as the by-path system, and gives distribution for both calling and called subscribers. Developments on these lines are being proceeded with, and the results obtained appear promising. I agree it is now time that a fixed percentage of lost calls allowable should be settled, also that the use of curves based on the law of probability can now be used by designers with confidence. It is, however, necessary that accurate figures on the existing traffic be obtained. On page 274 the author is not quite clear. The figure 17·4 per cent for the Post Office system means subscribers actually engaged, not junctions engaged. In computing lost calls, that may be allowable on a full automatic exchange. I have often used the percentage figure of the existing engaged calls during the busy hour of any exchange, and working on the law of probability have found out what decreases in the percentage the instantaneous disconnnection would produce in this number. As an example, assume that busy-hour traffic on a manual exchange gives 17·4 per cent of the subscribers engaged. On an automatic exchange the instantaneous disconnection alone, without allowing for any reduction in the holding time due to other reasons, would reduce this figure by 1·7 per cent and thus allow for 17 calls per 1,000 to be choked by the switches. I would not, of course, recommend choking or delaying such a large number, but the figure shows to how great an extent the calls may be choked without depreciating the service below manual standards. It is well known that an operator's efficiency falls as she covers more positions. As peak loads are usually only for 2 hours out of the 24, the operator's average day load is decreased enormously; of course, it would not be economical to keep all positions filled during the slacker hours. Fig. B shows a mean curve of that given by Mr. Maycock in the *Post Office Electrical Engineers' Journal*, of a number of operators on duty.

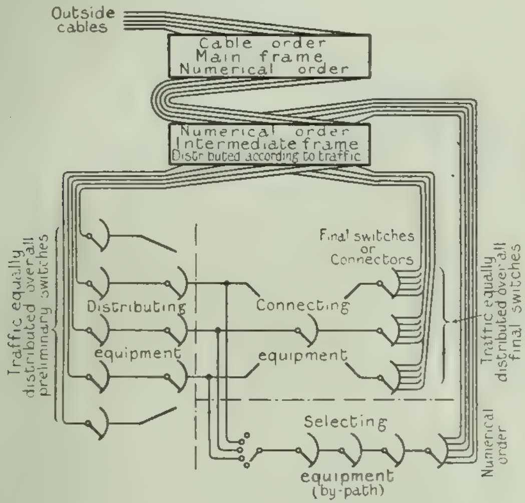
Outside cables
Cable order
Main frame
Numerical order
Numerical order
Intermediate frame
Distributed according to traffic
Traffic equally distributed over all preliminary switches
Distributing
equipment
Connecting
equipment
Final switches or Connectors
Traffic equally distributed over all final switches
Selecting
equipment (by-path)
Numerical order

FIG. A.—By-path switching system.

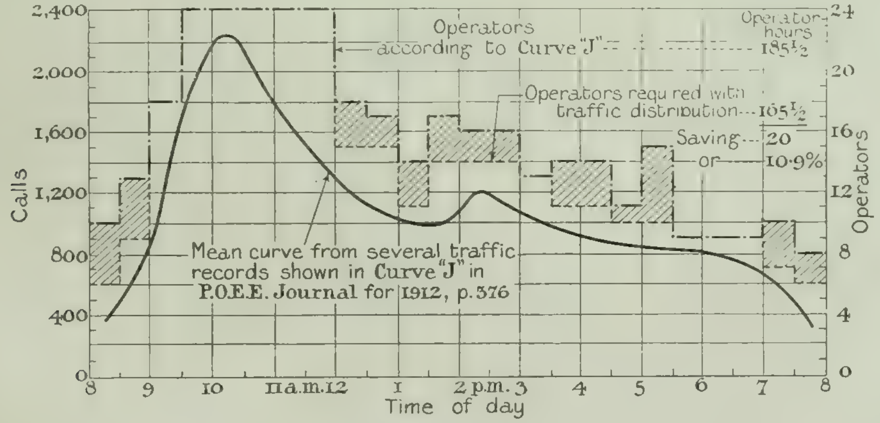

FIG. B.—Hampstead Exchange. Relation between staff and traffic, with and without traffic distribution.

The shaded portion I have added as being the number of operators required if a distributing system were fitted. The effect of distribution has the advantage of making the switchboard like a concertina, open at the busy periods and closed down gradually as required during the slacker hours. Now if added to this one can decrease the operator's work by other mechanical appliances such as dispensing with cords, plugs, multiple jacks, etc., one can readily see that the load can be increased and a great saving in operators obtained. The curve shows a very low busy-hour load. There are only 24 operators for 2,250 calls, or approximately 93 calls per position. This means that even when an operator is covering more than one position she can still be under-loaded, so that the example is by no means favourable to the case for distribution. To show the service given with a load of 600 calls, Fig. C gives the speed of answer on the Amsterdam semi-automatic exchange, also the "standard of answer" used by the late National Telephone Company, together with data from exchanges I and J in the paper. The National Telephone curve is not the best that can be obtained on manual service, but it can be taken, I think, as a fair standard for manual equipments. I am afraid the author's manual standard is not often worked up to, and on this score he cannot be accused of favouring machine switching as against manual. It will be seen from these curves that although the loads taken are higher than the late Telephone Company's standard, the service is greatly improved as the long waits are reduced. The duration of connec-

Mr. Laidlaw.

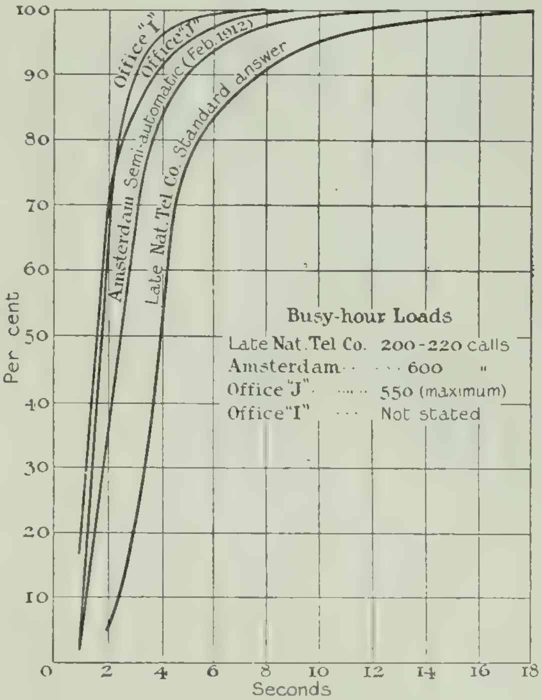

FIG. C.—Speed of answer for different systems.

[illegible] on an automatic exchange [illegible] I have been unable to account for this and can only assume that the subscriber finds the service [illegible] get through. [illegible] the calling rate [illegible] The following figures of maintenance taken from small private exchanges varying from 25 to 200 [illegible] of interest. These exchanges [illegible] fitted in munition factories are in use night and day and have been in operation on the average for 2 years. Of 18 exchanges with 1,100 lines working, the man-hours per line per year work out at 2·6. This includes equipment, instruments, and line plant. The class of man maintaining these equipments is the usual handyman employed about the works maintaining the electric light, etc. When the [illegible] the necessary routine tests and the parts to be watched on the exchange equipment and station apparatus, and up to now wherever the exchanges have been fitted no trouble has been experienced. Of course, from their size, the exchanges are practically unattended. The results bear out the author's figures, but it must be remembered these equipments have less apparatus per line than a large exchange. The records of service and faults given in the paper are extremely valuable and show that the working of machine-switching equipments have now arrived at a state when correct data can be obtained and facts instead of opinions expressed.

I have attempted to form, from the paper, a conclusion as to what value the use of automatic machinery of good manufacture would be, and it appears to me to be this:—

(1) A very much higher grade of service is rendered than that at present obtainable on manual equipment.

(2) The annual charges are comparable with manual and may possibly be less.

(3) The system is very much more flexible from a line-[illegible] The adaptability of automatic [illegible]hing to changes, and the more efficient use of line plant generally, may possibly warrant incurring large capital charges on exchange equipment. External plant forms approximately 60 to 70 per cent of the total value of a telephone administration's investment.

(4) Full automatic appears to be the most promising service for the majority of cases.

(5) Semi-automatic equipments with call distribution and supervision may be desirable in some cases, and especially during transition periods to full automatic. The question of whether supervision [illegible] doubtful, especially in self-contained areas, as from [illegible]

(6) [illegible] pments are taking place [illegible]

[illegible] relays will do all that the systems referred to by the author will do. The latter undoubtedly give excellent service, but I cannot bring myself to think that they are by any means the last word in automatic telephony. Will a system consisting of a large number of relays, motors, and machine-switching gear compete with, and do the work of, an automatic exchange better or more cheaply than one consisting of relays only? In the relay system there is no apparatus and no motion other than the ordinary operation of a relay to do the whole work of selection and connection, and the plant is not subject to difficulties owing to the inertia of comparatively heavy switches. No work whatever is done except when a call is actually being connected. A relay system will work with much greater variation of voltage and allows much greater variation in the speed of the calling device. The time required for a call will therefore be less than in any other system. Unfortunately I cannot give particulars such as the author does with regard to maintenance and other costs, but it does appear, and is borne out by our experience with some small plants which we have working, that the maintenance cost of relay systems must be very small. We hope to get valuable data from a 1,000-line plant now installed in Stockholm. The whole movement of a relay is so minute that the wear and tear of a plant may surely reasonably be expected to be very small. We have not yet found a fault due to dirty contact. A plant consisting of relays such as all telephone engineers are accustomed to handling in central battery exchanges would be much more easily dealt with by them than one which is a combination of electrical and mechanical apparatus. The well-known reliability of telephone relays confirms our experience that the maintenance of a relay automatic plant must be low. I well remember that when passing through Christiania I inspected the main exchange there and noticed a very large cupboard fixed high up on the wall, and I was told that it contained the relays. As they were so pressed for room they had put the cupboard there, because once the relays had settled down to work they required no further attention. The author says that the difficulty of obtaining men of sufficient skill and training to maintain automatic equipment has often been unduly emphasized; but although this may be so, the difficulty would be further reduced by the substitution of apparatus which is entirely a repetition of the same style of parts. As a manufacturing problem, relays and nothing but relays is surely the ideal solution.

Colonel Clay.

MR. A. J. [illegible] In the Post Office we [illegible] the importance of this subject that we have under trial five different systems of automatic switching. In addition, not quite in the sense of semi-automatic, but in the sense of securing automatic distribution of work which is essentially "manual" in connection with the trunk system, we have various aids which are of the automatic type—devices in aid of trunk-working itself or in its relation to the ordinary local service. Standardization in regard to [illegible] very far off. We have taken one practical step in that direction by securing that the user of the telephone shall have the same form of dial [illegible] of the five systems of automatics he may be connected. But the present state of essential change by progress puts the tubbs. general question of standardization out of range. Apart, however, from standardization, the Post Office engineer has to face the problem of interconnection of all or any of the numerous systems. Comparison of this between the mother art of telegraphy, and telephonic working, shows how essentially different and more complex the latter problem is bound to be. In telegraphy we have automatic working, the ordinary Morse system, the single needle, the A B C, and the very great development of printing telegraphs; but the problem of their combined use in one office is simple because the various systems work quite independently on different circuits. When, however, we come to the telephone business, there is no question of re-transmission, but through connection of any combination of parts of the whole of the system must be possible. The assimilation of automatics to this matter of through-switching is particularly difficult.

ir. Mr. D. Sinclair: So far back as 1883 I took out a patent for an automatic telephone exchange, and I believe the model is in the possession of the Institution. It worked for a year or two. Those were the days of single earth-circuit lines, but it gave place to a manual system as a general rule. From that day to this, however, I never lost my faith in automatic telephones, and I have recommended the system in season and out of season. I am very sorry that the author has more or less changed some of the old familiar names. He has called the connector a new name, and the selector also; one he terms "the seeker" and the other "the chooser." I would have preferred—and I think many of the old telephone engineers would have preferred—that he had adhered to the old names, and it will be noticed that in his drawings he reverts again to the old, well-known names.

itken. Mr. W. Aitken: I think the value of the paper would be enhanced if the author could supply a diagram, so that the *Journal* would contain a complete record of the system. The author has described more particularly the semi-automatic system, not I presume because he favours that more than the full automatic, but because, as he told us in his introductory remarks, he leaves that to the purchaser. I read before the Institution in May, 1911, a paper* on the Strowger automatic system, and it is interesting to note the different outlook to-day on the subject. Then most of the speakers were a little doubtful about the position they should take up in regard to automatic telephony. To-day it is taken for granted that the automatic telephone is the right thing. The automatic system has made good, and is now in use in every progressive country in the world. There are only two distinctive systems in use, the Strowger system and that described by the author, the one working by a ratchet and motor magnet and the other by power-driven shafting. Both are excellent in their way, and both have given good results, but it is doubtful whether they are the last word on the subject. We have had shown on the screen a "Panel" system, and I believe the author's firm have still another system in the development stage, so that there is not likely to be standardization and finality for a long time yet. Another system that has been referred to to-night is the relay system. The relay system is wonderful in its efficiency and its simplicity, and in my opinion it scores in some respects over the other systems. The author states on page 266 that there are three limitations to the switching system, namely, "the time of switching, the cost, and the number of machines," also that "of these the time limit within which the switching operation must be completed has imposed the most rigid restrictions." That is perfectly true of the two rotating switch systems, but the latter remark does not apply to a relay system because the action is instantaneous. The action of one line connecting to another of a group is instantaneous whether it be to the first or the last line of a group, whereas in machine switching there is a different time interval between making the first or the last contact. On page 268 the author says "The subsequent cost of maintenance is, however, of weight, since this cost is affected in a more important way by the multiplication of moving parts than it is by the multiplication of fixed parts." In a relay system the movement is only a fraction of an inch and there is practically no wear and tear; there are no moving parts analogous to machine switches. When a relay system is first considered, one jumps to the conclusion that, as a relay can only move as a two-way switch, to get one circuit having access to a considerable plurality it is necessary to have as many relays for each switching unit as there are circuits. That is not the case. By a particular combination of relays and a particular arrangement of wiring the number of relays can be greatly reduced. The "carriage call" arrangement is most interesting, and is a very fine application of a device that was known to some extent some years ago in this country. Mr. Arthur Thomson in his "Dumb-operating" telephone system was the first to give such a visual signal to the operator, but in a much cruder form than this. With regard to the question of maintenance mentioned in the paper, it is interesting to note how the figures given by the author confirm the figures I gave in 1911, which were then taken with a grain of salt. Some of the engineers who criticized my paper doubted the correctness of the statement that in an automatic exchange with 7,500 lines at Grand Rapids, U.S.A., the expenditure for renewal of parts was only 1.8 cents per line per annum. The author's figures give a still lower sum than that, so that apparently the maintenance of automatic systems is going to be a very small matter indeed. Mr. Aitken.

Mr. Anson. Mr. B. O. Anson: In Fig. 9 the author presents curves showing the maximum number of simultaneous calls that may be expected to occur with a given volume of traffic. These curves are based upon mathematical investigations corrected by practical experience. Curves of this type are not new, being in general use in telephone administrations for the purpose of controlling the provision of junction circuits between manual exchanges. It will be noticed that the curves shown in Fig. 9 are for calls having an average holding time of 2 minutes. It is customary to prepare curves showing different holding times, but an examination of a large number of curves that have come under the notice of the British Post Office shows that they are all of the same family, and that the independent variable is not the call but is what the author has described as the call-minute. In the Post Office curve mentioned in Table 6 the number of simultaneous calls was plotted against the T C (call-minute) values. The adoption of T C as the independent variable indicates an important difference between manual and automatic tele-

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* *Journal I.E.E.*, 1911, vol. 47, p. 651.

Mr. Anson manual practice. At manual exchanges (with the exception of junction circuit provision) the important consideration is the number of calls that a subscriber originates, or the number of calls handled by an operator, but when we come to consider machine-switching devices the [illegible] is not of such importance: the question at issue is not what the machine will connect but what it will carry having due regard to the average length of conversation. Consequently the holding time begins to assume added importance and its appearance in the base line in the traffic curves is explained. It will be realized that there are two quite distinct attitudes of mind with regard to traffic curves as affecting the design of automatic plant. The first is that of the contractor who has plant to sell, and the other is that of the administration which purchases. In the Post Office we found it inexpedient to adopt the standard curve or formula of any particular contractor or foreign telephone administration and constructed an arbitrary curve for our own use. This curve was constructed by reducing all other available curves to the T C basis, plotting them together on the same sheet and then drawing an independent curve with such precautions as were needful to safeguard our interests; the new curve being drawn on the paper within the region of the other plotted curves. Table 6 shows the effect of calculating the size of a large group of switches using the formulæ of the three different systems. I think it is only right to explain that the Post Office chart was not intended for use in this manner. It is believed that the second and third curves in Table 6 are used for calculations when the holding time is known with precision and are therefore an instrument of precision in the hands of manufacturers wishing to design plant which will have the greatest traffic-carrying capacity. The Post Office curve on the other hand was constructed with the object of using holding-time figures obtained under manual conditions as a guide for the installation of a new automatic exchange. The resulting calculations concern small groups. We have here two important points to consider; first, that holding-time figures obtained at one period do not necessarily apply at another, in other words, telephone traffic varies in this respect in a number of devious ways. The busy-hour holding time is generally shorter than the corresponding figure for the day's average. The holding time for both the day and busy hour differ at different seasons of the year, and, further, the holding time in all its aspects is likely to vary as the exchange grows and junction traffic increases in volume. The second important aspect of the case is that the very fact of an exchange being converted from manual to automatic working alters the conditions and leads to a reduction in the holding time, and consequently the use of manual figures is likely to lead to an over-estimate of the number of switches demanded in the contract specification. This tendency to inflate the number of switches required is one that cannot be evaluated upon present knowledge, but whatever that tendency may be the Post Office curve [illegible] occupies the mean position amongst the three illustrations given by the author. It should be observed that [illegible] curves of [illegible] may be taken as represented by the [illegible] in their application. It can be stated without [illegible] that no telephone administration has sufficient confidence both in its traffic statistics and its traffic curve to permit it to make the necessary calculations, and then connect subscribers to the automatic plant up to its full calculated capacity. Such a practice would undoubtedly produce a breakdown, and consequently there are very real reasons why the telephone administration cannot in its actual operations place very great reliance upon traffic curves of any kind, however precise they may be in their scientific basis. It appears, therefore, that although the Post Office chart is arbitrary and different from other standards that have been adopted, there is no reason to think that it is unsatisfactory having regard to the facts indicated above, which in practice seriously limit the application of traffic curves. It is quite true that in placing orders for telephone plant upon a competitive basis, it is necessary to make allowance for equipment grouped in different ways by different contractors, and, of course, the application of a specific curve theoretically tends to penalize one or other type of plant according to the nature of the standard curve adopted. In preparing the Post Office chart, however, this matter was not overlooked, and it was considered that calculations of traffic-carrying capacity in all except special cases would be concerned not with such large numbers of switches as those indicated by the author, but with figures that correspond to something considerably less than 100 switches. Usually the calculations for small groups give a result which calls for a number of switches plus a fraction of a switch, and as that fraction must either be ignored or expanded to a whole switch the error thus introduced is likely to be greater than that involved in the use of the different types of traffic chart. With regard to the Western Electric automatic system, the author has shown that the trunk-hunting facility affords an additional traffic safeguard. At one time I was very sceptical as to the practical value of this facility, but events have shown that it is of great utility. I have to-day received information from a Post Office exchange of the Western Electric Company's type which shows that in a particular case (where the traffic has grown abnormally and alterations are pending) the maximum number of group switches recently hunting at one time which actually completed the connection was nine. All nine calls were completed within 2 or 2½ minutes; showing that subscribers will wait on the line when they know that in due course a connection is likely to be effective. In some cases where the called subscriber was engaged the group switch secured a final switch, got the "engaged signal," was released, and the same final switch was taken up again in 8 to 10 seconds. Cases have been observed in which one final switch has been taken up in this way and released again five successive times in less than a minute.

(*Communicated*): The author deals with the question of annual costs. We have reason to think that the maintenance expenditure will be comparable with that of manual exchanges for all automatic plants of 1,000 lines and upwards. There will be some increase in expenditure but, as the author states, the cost will depend almost entirely upon the extent to which the operating administration has confidence in leaving the plant unattended. It appears clear, therefore, that the financial balance will depend upon a saving in operating costs, as set against financial appropriations due to the higher first cost of automatic as compared with manual plant. These finan-

Anson.

cial items are of a somewhat elusive character when considered from the point of view of an administration which must decide in the present what shall be its policy in the future. It is impossible to say what will be the rate of interest on capital in this country looking forward a number of years. The depreciation fund of course will be influenced not only by changes in the rate of interest, but also by the estimated life of the plant. The estimated life of the plant is influenced by its renewability. Automatic plant does not suffer in this respect from the limitations which the subscriber's multiple imposes upon manual plant. The experience of many years clearly indicate that the tendency of operators' wages is to increase, whilst it is also certain that, other things being equal, the tendency of the first cost of the plant is to decrease if the manufacturers are given sufficient orders to enable them to pay off their development and to introduce a high grade of organization into their factories. These two tendencies in themselves indicate that the adoption of automatic plant is not so much a matter of the application of present financial charges, as the application of such charges projected to what we think they are likely to be a number of years hence. This solid fact we have, however; that the difference between automatic and manual working cannot be seriously to the disadvantage of the automatic system even upon existing conditions, whereas there is every prospect of progressive improvement with the lapse of time.

thory.

Mr. E. A. PETITHORY: We find that almost at the beginning of the telephone art, engineers were seeking for and inventing methods of setting up connections by mechanical means. The first known patent was taken out in 1879 by Connolly and McTighe, then follow two others in 1881, while the first semi-automatic equipment patent was taken out in November 1881. All of these were step-by-step mechanism. In April 1883 a patent was taken out for a system using power drive. In 1889 Smith took out several patents for telegraph trunk-working using power drive. Strowger in 1889 was the first to evolve a fairly successful system, the familiar pill box, as it is called, having vertical and rotary motions. This patent may be called the basis of successful step-by-step systems. Callender's inventions of 1893–94 anticipated a large number of the modern requirements, such as two-wire system (no earth return); percentage system, i.e. supplying only enough apparatus to perform the switching at the busy hour; primary and secondary circuit selectors; storage of calls, and power drive. The progress from that point has been most rapid, most of the failures resulting from not appreciating the needs of the traffic engineer on the one hand, and costs and good construction on the other. I agree with the author's statement at the foot of page 267 *re* size of machine. A study was made some years ago to determine whether the decimal system and the 100-line switch bank should be retained. It is feasible to use banks larger than 100 with a decimal system, but to save complication they are usually kept to multiples of 100. It was found that about 90 per cent of the exchanges in this country are below 1,000 lines, and Fig. D, prepared from some of the data collected at that time, shows several curves giving relative cost ratios of switch and field for various sizes of fields. On the curves shown, the sizes of fields (banks) are represented by the abscissæ, while the total values of switching apparatus (expressed in values of one terminal) are plotted as ordinates.

Mr. Petithory.

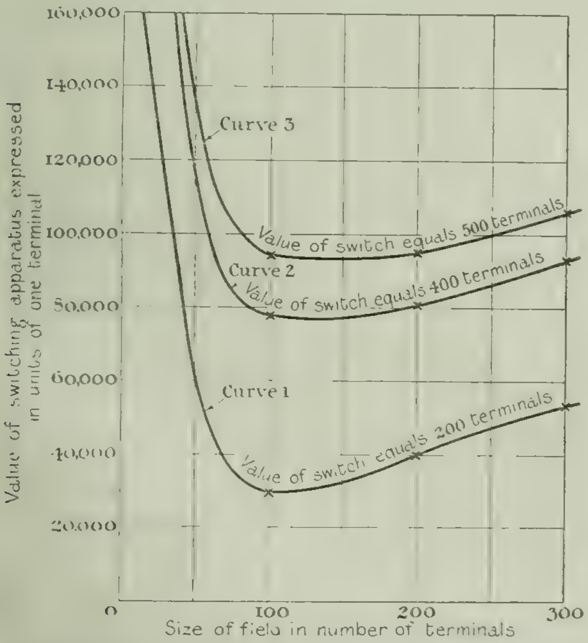

FIG. D.—Relative cost ratios between size of field and switching apparatus required for a 1,000-line exchange.

No. of calls per day = 10.
Calls per busy hour = 1·3.
Calls lost per 1,000 per day = 1.

Basic Figures.

Size of exchange	1,000 lines
No. of calls per day	10
No. of calls per busy hour ...	1·3
No. of calls allowed for being lost per 1,000 (by "probability" calculation)	1

On Curve 1 the value of the switch equals 200 terminals, the value of field being equal to the size of field, i.e. 100-line field has a cost value of 100 terminals, 200 lines, 200 terminals, etc.

On Curve 2 the value of the switch equals 400 terminals with field as on Curve 1.

On Curve 3 the value of the switch equals 500 terminals with field as on Curve 1.

It will be seen from Curve 3 that there is a slight advantage in favour of 100-line fields as compared with 200- and 300-line fields (or banks). Curve 3 probably represents the actual cost ratio of switch to bank on switching apparatus at present in use, better than Curves 1 and 2.

Fig. 1. in the paper would be of greater value for comparison if the number of calls per busy hour and the relative cost value of the switches and terminals were given. Also the basis of the curve, i.e. an exchange of 100,000 lines, while ideal from the manufacturing point of view, can hardly give just comparison for small and medium-sized exchanges. *Re* the form of mechanism to be used, one of the most successful and common is the clock, which combines both power drive and step by step. Step-by-step mechanism would appear to be the most simple. The switches accept the dialling impulses direct, whereas with power-driven mechanism, owing to the lower speed, it appears necessary to complicate the apparatus by storing or register devices, in order that the impulses are not lost and to give them out at a rate of speed to suit the switches. Obviously a system that can accept impulses direct appears preferable, other things being equal. I cannot agree with the author's statement on page 267 that step-by-step apparatus need be of extra light construction owing to its higher speed and the work to be performed, and therefore of less durability, as from observations I have made it would appear that the resultant forces due to moving the wipers, and the energy to be dissipated in stopping, are about the same on both power-driven and step-by-step apparatus. This seems to be borne out by the fact of its being necessary to provide a brake to ensure the wipers of the power-driven switch stopping correctly on the chosen contacts. Ratchet-drive apparatus is now being successfully worked at speeds up to 60 steps per second, and with switches properly distributed to suit the traffic requirements this speed has been found satisfactory up to the present. The line finder described in the paper contains 60 sets of terminals being driven over at 20 steps per second, requiring 3 seconds to pass over the 60 sets. As the subscriber cannot commence dialling until the line finder has picked up the calling line, presumably in extreme cases he will have to wait 3 seconds after removing the receiver. With the usual step-by-step system there is no observable waiting time as the pre-selector or line finder has reached its required point in from $\frac{1}{8}$ to $\frac{1}{4}$ second, and the subscriber dials at once after the receiver is removed. The system of the future may be a combination of step-by-step and power-driven apparatus.

Mr. Ward. Mr. F. M. WARD: That telephone switching can be done satisfactorily by automatic means must, I think, be regarded at this date as an accepted fact, although opinions may differ considerably as to the best way to attain the desired end. The author favours the use of power-driven machines of more or less massive construction, in which as much of the work as possible is done by mechanical means. I am, however, of the opinion that the tendency in the future will be to eliminate the mechanical features and to substitute for them equivalent electrical means. There are many examples in manual telephone development along these lines; for instance, the Western Electric Company in their manual junction boards originally used a ringing key which was depressed and released by the operator. They then employed a key which was depressed by the operator and held down by a latch, but was electromagnetically released by withdrawing the latch when the subscriber answered. The latch was soon replaced by an electromagnetic catch, but finally the keys were done away with altogether and the ringing is now controlled by relays. A similar tendency is already noticeable in automatic telephony. From experience during the past three years, on a system in which the whole of the switching and connecting is done by electrical means, i.e. simple relays, it has been found that the apparatus will work satisfactorily within very wide limits. [illegible] selectors will work reliably with a large variation of dial speed. This gets rid of one of the difficulties in full automatic systems. The hunting for an idle line is not done by a step-by-step movement, and is practically instantaneous. It therefore takes no longer to connect to the last trunk in a group, no matter how large that group may be, than it does to connect to the first trunk in a group. As was to be expected we have also found that as the power needed by the electromagnets of relays is so small, destructive sparking is practically eliminated. The battery voltage may also vary considerably without causing trouble, and the number of cells can be varied to meet the local conditions. We have plants working successfully with pressures of 24 volts, 32 volts, and 44 volts. Further, it appears to me that machine-switching gear will demand maintenance men with a considerable amount of mechanical skill in addition to electrical knowledge, whereas a relay system seems to be a natural development of common-battery working, which will appeal to telephone men, as the apparatus has been familiar to them for the past 15 or 20 years. Moreover, I think it will be admitted that given a well-designed relay, with plenty of current and good contact pressure, the attention required will be a minimum. In conclusion, the point I desire particularly to make is, that while fully appreciating the very valuable work which the author has done in automatic telephony and the state of perfection to which the Western Electric system has been brought, there has been so much activity in the art during the past few years that I doubt very much whether we have yet reached anything like finality.

Mr. W. H. GRINSTED: Since 1906 I have been very interested in the subject of probability or chance play,

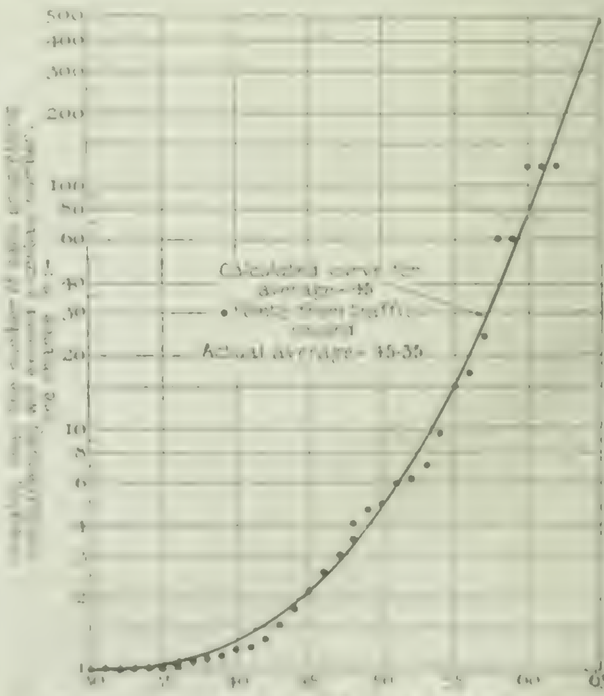

FIG. 1.—Comparison of calculated number of [illegible] connections with [illegible] May [illegible]

from the practical as well as the theoretical point of view. I fully agree with the author as to the use and significance nsted.

of the results obtained from the application of mathematical methods, and also as to the desirability of a uniform method of computing the numbers of machines required. Mr. Anson has pointed out that there are many factors which enter into an administration's considerations but do not affect the designer. I think that although this may be so, these methods should be of use to the administration in making comparisons between different systems, as well as to the manufacturer in selecting the most desirable arrangements of his switching gear. Probability charts and tables are of use to the automatic telephone engineer in the same way as tables of interest and sinking fund are to the accountant, enabling the automatic engineer to lay out his apparatus for the best results, just as the interest tables enable the accountant to choose the best way to lay out his money. The first step towards uniformity is to see that the mathematical methods used by the different computers give uniform results. I have therefore looked into the question as to how closely the author's computed figures agree with those computed by my methods. I will give one or two examples of these results. In Table 4 series of figures are given showing the observed and calculated distribution of calls over a group of 10 trunks. Taking column A, my calculated figures compare with the author's as follows:—

	McBerty	Grinsted
1	44	44
2	42	43
3	38	39
4	32	32
5	25	24
6	17	17
7	10	10
8	6	5
9	3	3
10	1	1

Again, taking the curves shown in Fig. 8, my computed points fall almost exactly on the author's dotted curve. I do not know, of course, what mathematical methods have been used by the author. Mine were developed in 1907 and are given in the *Post Office Electrical Engineers' Journal* for April 1915. The next step is to ensure that the mathematical results correspond to the practical. The author has already given conclusive evidence on this point, but I should like to confirm it by just one example. The curve shown in Fig. E gives the calculated probability of the number of calls simultaneously in progress at any moment exceeding the numbers given at the foot of the chart. The points plotted are from an actual traffic record made in May 1911 by the engineer in charge of a large automatic exchange purely for his own purposes, and without any connection with, or in fact any knowledge of, the theoretical results. The agreement is striking. Results like these, I think, show that the mathematical methods can be used with confidence. The author shows in Table 6 what different numbers of switches and calls lost result from the different charts and formulæ used at present. Fig. F shows a comparison between these charts and formulæ applied to small groups of lines. The curves show the percentage of lost calls which will result when lines or

Mr. Grinsted.

switches are provided for given call densities according to the various charts. The scales below the horizontal axis show the numbers of lines which are provided by each method. Curve A shows the conditions when junctions are provided in accordance with the practice followed by the late National Telephone Company between manual exchanges. It will be noticed that on very small groups of junctions as many as 2 or 3 per cent may be choked on account of junctions busy. This is, of course, intentional on account of the high cost of providing additional circuits on small and in most cases lengthy routes. The Post Office chart referred to in Table 6 (Curve B) modifies this in the small groups, but follows the Telephone Company's curve for larger traffic. The chances given by the formula quoted by the author (Curve C) are remarkably uniform for all groups, seeing that the formula is, I believe, empirical. Curve and scale (D) represent the results if the lines are provided in such a way that one call per 1,000 is lost due to all the junctions in the group being engaged. It should be noted that when any of the methods illustrated are used for fixing the number of switches or trunks required in every group throughout an automatic exchange, the percentage of calls shown is lost at each operation of selecting. Thus, assuming an exchange with first and second pre-selectors, first and second selectors and connectors, the switching equipment being provided exactly in accordance with scale (C), roughly 0·5 per cent of the busy-hour traffic would be lost in testing at the second pre-selectors, at the first and second selectors, and at the connectors, so that the overall loss for the busy hour would be 2·0 per cent. The curves shown illustrate roughly the basis on which things are being worked now. The fixing of the standard to be worked to in the future must be left to the administrations operating the equipments. The author puts forward a loss of 1 per 1,000 on the day's calls, amounting on his showing to 4 per 1,000 on the busy-hour calls. This is on the basis of 2 busy hours in the day. I

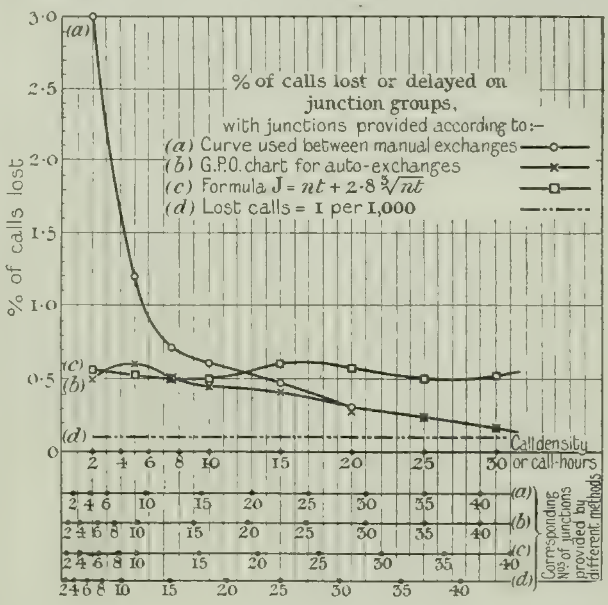

Fig. F.

[illegible] traffic curves. The afternoon peak is generally considerably lower than the morning peak, but in the morning the actual peak rarely lasts more than 1 hour. The author apparently takes any hour in which the traffic is more than 80 per cent of the actual peak as a busy hour. This scarcely seems justifiable, since the percentage of lost calls decreases very rapidly as the traffic falls off. I would suggest, therefore, adhering to the one lost call per 1,000 on the day's calls, but assuming only one busy hour, so allowing 8 lost calls per 1,000 on the busy hour. This standard, of course, would apply inside the exchange only; when outside junctions enter into the question it is possible some modification might be necessary. Certainly the standard suggested does not err on the side of bad service when one remembers that 170 per 1,000 of the busy-hour calls are choked at the called subscriber's line, and that, as Mr. Laidlaw has pointed out, the instantaneous disconnect alone would permit 17 calls per 1,000 to be choked in the equipment without making the service worse than on the manual system.

Mr. J. Lee: The author does not always use each word with its own connotation. Even the American word "office" and the English word "exchange" are used occasionally in the same sentence with precisely the same meaning. We want our nomenclature standardized. Statistics also should be collected. Old-fashioned men are bound to be somewhat alarmed with the high traffic loads given on page 289. It would seem to us that if the semi-automatic system can carry these loads it defeats itself. The amount of time given to each subscriber is so small as not to be an appreciable service, and it is manifest that the difference between a service of this kind and full automatic is very small. At the same time one can see the value of a semi-automatic system in the stages of development of a vast area like London, from full manual to full automatic, and it seems to me that that function of the semi-automatic system is the special value which is proved by this paper. We get another aspect of the case when we consider timed distribution. This is all right where the subscriber merely asks for a number and there is nothing more to be done but to connect him; but it is obvious that any demands which occasion time, any uncertainty as regards numbers or exchanges, any use of a coin box or a [illegible] this timed distribution. I should like to know something about Exchange M, which with 100 per cent junction traffic seems to have a connecting time of 18 seconds. Even in respect of the loads on this exchange and the answering time we seem to have much to learn, and it may be that it is a telephone area specially favoured with every advantage, including an efficient public.

[illegible] been found feasible for commercial service to propel the [illegible] 100 contacts per second and yet [illegible] with a larger number of contacts than 100. There is a considerable difference in the number of motor switches between no lines and 100 lines, but between 100 and 200 the difference is not considerable, and from 200 to 1,000 the curve is very flat indeed. When it is borne in mind that as soon as we depart from the simple decimal system at the exchange, auxiliary devices in respect of registers for storing the decimal signals and translating them into non-decimal impulses are requisite, it appears to me that the adoption of switch banks for larger numbers than 100 lines is of doubtful advantage. I should like the author to tell us whether, in regard to the curve representing the number of switches, the registering devices which are required for anything over 100 lines have been taken into account.

Mr. Hedley Mr. J. Hedley (*communicated*): With regard to the number of fixed terminals, it is possible to obtain a similar efficiency with 17 switches with 200 fixed terminals, as with 20 switches for systems with 100 fixed terminals; e.g. assume that 10 switches are required for a group of 100 lines with a call duration (T C) of 5·2; for two such 100-line groups, each with T C of 5·2, 20 switches are required. With a 200-line group of similar T C, i.e. 10·4, only 17 switches are required. In connection with exchanges provided by the Western Electric Company this reduction was allowed, i.e. each contractor provided switches for the Post Office to give the same probability of congestion occurring. Economy in the provision of switches therefore results by adopting fixed terminals for 200 lines as compared with 100 lines. With regard to the percentage of calls delayed owing to the deficiency of junctions in manual exchanges, referred to by the author on pages 271 and 272, the curve used by the Post Office for junction provision is admittedly conservative, the probability of congestion being of the order of 1 in 30; for the initial fitted capacity of an automatic exchange there is little advantage in providing switches very much in excess of manual practice, as the probability for congestion occurring during the initial stage after conversion to automatic working—when the number of working subscribers is much less than the fitted capacity, and the holding time reduced for automatic working as compared with manual—will be negligible. The all-important point for manufacturers to concentrate upon is to design their systems so that the cabling and terminal arrangements and switch jack assembly will enable the user with facility to fit extra switches throughout the various channels in an automatic exchange equipment, to cater for the traffic as found necessary under actual working conditions.

Mr. S. H. Pook (*communicated*): The paper indicates the detailed way in which the traffic side of the question is investigated, but it appears that some engineers strive after an ideal which can only be attained at excessive cost. [illegible] loss or delay of 4 per cent of the calls in the busy hour under certain conditions. A higher efficiency than this appears [illegible] high efficiency as 0·1 per cent for the day which, I believe, is the figure adopted by some makers in the absence of a definite specification from the customer. An efficiency of 0·1 per cent means that an average subscriber will only be inconvenienced about twice a year, and when it is remembered [illegible] and junctions engaged" are, say, 15 per cent on a good manual system, and that the change to automatic cannot materially reduce this, it seems that money is being spent on refinements which are not appreciated by the subscriber and which do not earn a proportionate amount for the administration. From a rough calculation it appears that upwards of 10 per cent of the switches would be saved if a figure of total delays of 0·25 per cent for the whole day instead of 0·1 per cent is assumed. I have not the information to say what saving this represents in the first cost of equipment, but I suggest that a curve setting out percentage delays against equipment first costs would be of great assistance to the operating engineer. Fig. 9 suggests a large saving in cost if 1 per cent delays on the whole day can be tolerated, and it is conceivable that manual equipment to take the peak load might be a success if the automatic equipment were designed at this or a lower efficiency. Apparatus might be arranged to put the calling subscriber through to a manual operator in the event of the switches being busy, and this operator might have access to all lines, either by a multiple in front of her or via the connectors. In this way standing costs might be reduced sufficiently to outweigh the additional labour costs involved. One operator could deal with the delayed calls on a large exchange and would only be employed in the busy hours, leaving the rest of the day free for other work. Smaller equipments would be designed on such an efficiency as would yield enough "delay work" during the busy hour to keep one operator busy. Statistics could be kept of the portions of apparatus causing most delays, and thus accurate figures would be available for each extension and more switches could be added if necessary as the exchange grows, always keeping the "delay work" within the capabilities of one, or whatever is found to be the economical number of operators. The justification of such a scheme might not be so marked in the case of a system which continually hunts as in one which returns an engaged signal for each deficiency of trunks; possibly it is worth consideration in both cases. I have not the material with which to work a case out in detail; the author can no doubt say at once if the scheme is practicable and likely to be economical.

Mr. F. R. McBerty (*in reply*): Mr. Gill has raised a number of questions about the percentages of errors in machine-switching equipments, which I shall answer by reference to Table A.

Mr. McBerty.

The distinction between errors in operation and mechanical faults in the equipment is difficult to make and to preserve in the office records. In a full automatic system reports of errors largely come from subscribers, but tend to disappear as the percentage becomes small, and have little direct effect upon the faults cleared. The faults must be discovered by routine tests, in which the fault causing an error is at once located and cleared, so that it does not produce repeated errors as in actual service. In semi-automatic service without supervision the same conditions apply to errors and faults of certain kinds, but ordinarily not to faults in the progress of selection; and the observations of operators must be supplemented by routine tests. In semi-automatic systems with supervision the connection is throughout under the observation of the operator, who if properly trained can return a complete report of errors, which in a large percentage of cases can be traced to their causes, and may not be repeated. In certain full-automatic exchanges operated by the British Post Office a like observation by the operators of the traffic through the toll boards furnishes useful information of developing faults. In the above table the "trials" (1, 6, 7) were tests made under carefully worked-out methods for ensuring accuracy, applied by trained men before the cut-over of the exchange, and give a reliable measure of the accuracy of mechanical switching. The results in operation are records of errors reported by subscribers, operators, and patrols in the offices; Nos. 2 and 3 are the records of persons well-trained for the purpose and are quite reliable. Nos. 5 and 8 are the routine reports of the administrations operating the equipments. They probably show results which are below the actual occurrences, but as checked by the observations 4 and 9 by trained engineers, not much below. The observations include operator's errors. In office G no routine tests were made, the operator's reports of error being relied upon to keep the equipment in order; the records Nos. 5 of office I, and 7 and 8 of office J include routine tests. Information is at hand as to subscribers' errors only for office C in Table 9; in 3,151 service observations made by trained traffic observers 1·02 errors due to subscribers were observed, including wrong selections and accidental movements of the switch hook. There is no case in the offices listed in the tables in which the number of machines has been accurately worked out from the traffic records; the first case to the author's knowledge in which this was done was in the plans for the equipment of Christiania of about 30,000 lines, under the supervision of Mr. Abild, Chief Engineer of the Telegraph Adminstration, by Mr. P. V. Christensen. No data is at hand covering calls for information in semi-automatic systems. The deduction in respect of the higher number of man-hours required by administration-owned plants is interesting, but hardly warranted by the facts. The smaller exchanges require relatively more men, and these happen to be owned by administrations; also the oldest equipments require more maintenance labour. Only one of the equipments in the list, namely office H, is operated by the British Post Office. As to the labour of maintenance of automatic equipments by the British Post Office, the notes below will

Table A.

Errors and Faults.

No. of Test	Office	Record	Calls Observed	Errors, %	Faults Cleared, %
1	G	Trial	—	0·2	—
2	G	Operation	212,517	0·32	0·05
3	K_1	Operation	82,064	0·52	—
4	I	Observation	200	1·0*	0
5	I	Operation	84,264	—	0·015
6	J	Trial	123,753	0·087	—
7	J	Trial	2,797	0	0
8	J	Operation	186,928	—	0·096
9	J	Observation	700	0	0

* Wrong buttons pressed.

Mr. McBerty.

be interesting (Table B). They show the estimated man-hours per line per year for maintaining the whole inside office plant at six automatic exchanges for which records are available covering more than 6 months. Five have been omitted for the reason that they are small equipments and have not yet been sufficiently long in operation to be significant in this connection :—

TABLE B.

Man-hours per line per year (1910).

Size ...	0–500		500–1,000		1,000–1,500	1,500–4,000
Office ...	T	H	X	Y	W	Z
Average ...	8·2	9·7	6·6	8·1	9·6	6·2
Maximum ...	12·2	11·6	10·0	9·6	11·3	7·5
Minimum ...	5·6	7·8	6·0	7·4	7·6	4·8

The numbers of man-hours per line per year are estimated for 12 full months from actual experience over periods from 6 to 12 months. The average is estimated from the average of the months recorded, the maximum from the highest month, the minimum from the lowest month. The labour covers in these cases the maintenance of the office equipment including the automatic machinery, main and intermediate distributing frames, power plant, service meters, and manual switching equipment for toll or other purposes, but not wire chief or supervision. While the portion of this labour required by the mechanical switching equipment cannot be separated from the other labour, the total figures compare favourably with the labour of maintaining the mechanical switching equipment only shown in Table 9. Mr. Gill's observation that a larger percentage of delayed calls can be tolerated than of lost calls corresponds with results observed in practice; but the question as to the exact effect in delaying calls (in a system of registers or mechanism for repeated testing) is not now answerable. The manner of defining the calls [illegible] for the case—that is to specify one or several percentages of calls delayed for different numbers of seconds. The mathematical method of computing the delays is not, however, satisfactorily worked out, and insufficient statistical data is yet available to permit an empirical definition being formulated. Specifying a total number of seconds of delay together with a limited maximum delay fails to take account satisfactorily of peak loads in short intervals or in particular numerical groups, which may delay calls excessively in time or in number. Table 13 shows the average delay of calls in obtaining free trunks which results from arbitrarily reducing the numbers of trunks available in four different groups of final switches, I, II, III, IV. The delay was observed at the waiting register, being measured from the moment of choosing the brush of the group switch, through the time of seeking a final switch, to choosing the brush in the latter.

The indication of studies so far made is that without producing unreasonable delays of calls considerable reductions in the junction equipment can be made as compared with instantaneous testing and busy-back signalling, amounting perhaps to 10 per cent or even 20 per cent.

Mr. Laidlaw, I [illegible] that in groups of 200 lines 20 junctions per level are perhaps not warranted by traffic. It is found in designing exchanges with such groups that in nearly all fairly large equipments large groups are fully used in all numerical groups and for all selections excepting a limited number at the final switches or connectors. In the last case at low calling rates there will be considerable numbers of groups of 200 lines which do not require 20 junctions. The economies of large groups are therefore obtained for the great majority of the trunk groups. I agree with Mr. Laidlaw that considerable economies might be made if the assignment of the called lines in definite blocks served by a fixed number of junctions or switches could be avoided, but I am doubtful whether at present such arrangements can be produced which do not expend the savings from this feature in mechanism for bringing about the proper distribution of traffic. He might have emphasized even more strongly the assistance which call-distribution in semi-automatic systems affords in adjusting the operating force to the traffic curve. It is apparent on reference to Figs. 11 and 12 that, as the calling rate in the office diminishes, the team of operators will eventually be reduced to a point where the operators no longer work with the same efficiency and produce the same percentage of delays; but the efficiency is reduced and the delays are increased in a much less degree than in a manual equipment, while by reason of the brief handling time the operators are able to carry considerable rushes of calls without producing excessive delays. The provision is made in large equipments for monitor operators to take calls through the helping-out apparatus during periods of increasing load. The conclusions formulated by Mr. Laidlaw agree to a very gratifying degree with those of the author from the facts presented. As to the relative merits of full automatic and semi-automatic operating, however, my view is that the available machine-switching equipments are suitable for either manner of working; the constructor is prepared to furnish equipment for either service with no great difference in first cost or cost of maintenance, and the traffic engineers should now determine the conditions which may lead to a choice of the one or the other, or of both for differing conditions. I do not agree with Mr. Laidlaw, however, with respect to the value of operator's supervision of the connections in semi-automatic equipments. Such supervision of all connections perfects the mechanical

TABLE C.

Calls delayed by trunks, busy hour. Office 7.

No. of Test	Number of Trunks				Time of Seeking	Calls Delayed	Number of Calls
	I	II	III	IV			
1	16	15	15	18	—	0	—
2	9	6	6	9	3·2	1	120
3	9	6	6	9	2·8	0	49
4	9	6	6	9	3·6	1	70
5	7	5	5	6	7·7	25	122
6	6	5	5	6	8·4	45	183
7	6	5	5	6	9·1	25	71

switching equipment being kept in condition for excellent performance, and with such performance little actual telephonic interference is required. When the operator who makes a connection is able to come into the circuit as required, she is able to satisfy the user without occasioning repeated calls to operators who have had no share in the initial connection. Such service is peculiarly important in multi-office areas undergoing conversion, and in which semi-automatic equipments are operated together with manual boards in which supervision is still maintained.

All telephone engineers will observe the development of the relay-switching system described by Colonel Clay with great interest. The simplicity of the mechanical structure is attractive not only from the manufacturing point of view but in the working equipment. Such complexities and difficulties as characterize the system are mainly in fixed wiring and circuit networks, which may be expected to give little trouble. In the view of the author the question whether switching machines or switching relays will prevail in competition will be determined largely by considerations of cost.

Mr. Stubbs has referred to the difficulties which automatic working offers in respect to "through switching" in such complex networks as those operated by the Post Office. The difficulties of the problems here encountered are real and it cannot be said that solutions have yet been found for many of them equally satisfactory with those found for local switching problems. On the other hand it appears to many engineers highly probable that the introduction of machine-switching equipment for through working and switching at remote points can bring about very substantial improvements in service as well as substantial economies in trunk lines. The use of registers or similar mechanism permits considerable delays in the automatic choosing of lines, and also repeated selections to link together roundabout paths through the network, thus offering economies in plant. The electrical control of such switches as are now available is quite feasible over ranges which include a large proportion of the trunk traffic about cities, thus permitting the elimination of operators, with improvement in speed and accuracy of service.

I agree with Mr. Sinclair in his wish that acceptable names might be found for the elements which machine-switching systems have in common, but I have been unable to accept the names already existing as fully descriptive or satisfactory. There are, for example, no generic terms which distinguish switches seeking calling terminals and those choosing terminals. The term pre-selector frequently seems to have special reference to the Keith switch, and fails to include various forms of post-selectors like the line finder and the small seeking switch commonly known by the German name "Vorwahler." The distinction which is commonly made between selectors and connectors is not obvious, since either can perform the function of the other without other change than that of its position in the switching network. The designation of switches as first group switches or first group selectors, and final switches or final selectors would seem to be more logical.

The inclusion in the paper of circuit diagrams as suggested by Mr. Aitken appeared to me to be undesirable for several reasons, one of which is that a considerable variety of circuits would be required to exhibit the features described in the paper; and another that a long and detailed description is necessary for following the diagrams. A description of the semi-automatic system in considerable detail, with adequate diagrams and descriptions of the circuits, will be found in a paper read by Mr. J. Hedley before the London Centre of the Institution of Post Office Electrical Engineers on February 4, 1916, which is issued by the Librarian of that Institution.

Mr. McBerty.

Mr. Anson's advocacy of the time-calls or call-minutes curve employed by the Post Office for estimating the number of trunks and machines required is in accordance with my own preference. The charts commonly employed are computed for the 2-minute average holding time which was accepted for central battery manual service; the diminished holding time in automatic service, as well as the considerable deviations from the average which in estimating the machine equipment for automatic exchanges, are well worth taking into account, makes the time-call curve more readily applicable. Within the range of variation in holding time and hourly calling rate experienced in ordinary exchanges there is little difference between the time-call curve and the corresponding 2-minute holding-time curve.

As to the preference for empirical charts in place of general formulæ based upon the theory of probability, the latter would seem to have the advantage of more general applicability and of covering ranges over which statistical data cannot be obtained in manual working, and to which the empirical curves cannot be safely extended; and the probable percentage of lost or delayed calls can after all be obtained from the empirical curves only by resorting to the mathematical calculations. While it is clearly still desirable to employ the mathematical methods of estimating with caution and under suitable checks from experience with traffic, it is suggested that the estimates be safeguarded by the addition of factors of safety to be separately fixed and judiciously applied. Mr. Anson refers to the relation between first cost of machine-switching equipments and the quantity manufactured. This is an extremely important matter and one which the author may be pardoned for emphasizing as a controlling influence in the application of machine switching quite apart from the commercial aspect. The possibility of producing machine-switching systems is consequent upon modern methods of manufacture in quantity.

Among the comments made by Mr. Petithory I observe the suggestion that power-driven mechanism requires a complicated call-storing apparatus, the allusion being no doubt to the register. The statement is hardly correct, since a power-driven apparatus may be operated directly from the subscriber's station, and since also the register has a number of useful functions of which the control of the driving mechanism is not the most important. The speed of searching for a calling line cannot be estimated from that required by a single finder, for the reason that ordinarily several finders search for the calling line at the same moment; there is thus a relation between the time of selecting a calling line and the number of finders free for taking it. The time for taking up the calling line rarely reaches 3 seconds and ordinarily is well within 1 second.

I would amend the statement by Mr. Ward that the Western Electric Company in the development of the

Mr. McBerty.

[illegible] improvements [illegible] to the [illegible] in the direction of performing by power the work which had [illegible]. A relay may be regarded as a motor magnet driving a switch contact to either of two fixed points; and the conditions for [illegible] motor driving a switch member to the chosen one of a [illegible] the same sort of wear as mechanical switches, but are [illegible] subject to their own peculiar wear, which [illegible] place largely upon surfaces of platinum or other costly metal; and though they respond quickly, the speed bears a relation to the work performed, and varies greatly under variations of voltage or resistance. There seems to be in the field of telephone switching distinct opportunities for the application of this very interesting and latest arrival in the family of automatic switching mechanisms, though it seems probable that some considerable time and much experience of performance and cost will be necessary to demonstrate a general superiority.

In connection with Mr. Grinsted's contribution to the discussion and in the interests of historical sufficiency I should like to mention that the first substantial contribution to the theory of chance as applied to telephone traffic was made by Mr. M. C. Rorty in a paper accompanied by a series of charts read at my invitation before the Western Branch of the American Institute of Electrical Engineers in 1903. This paper so far as I am aware has not been printed, though it has become generally known and has formed the basis of much of the subsequent work. The chart showing the correspondence between the observed and the calculated arriving calls in a large exchange [illegible] significance will be appreciated. Mr. Grinsted rightly directs attention to the fact that the lost or delayed calls estimated at different points of congestion of a machine-switching system should be in some sense cumulative. It is necessary to mention, however, that in the case of lost calls those which are blocked at any stage of selection do not appear at the succeeding stages; that the losses due to peak loads in time apparently are not affected by the same conditions as those which appear in particular numerical groups; and that in the case of calls which are delayed [illegible], the quality of service cannot be determined by the simple summation of delays at different stages of selection.

It is not clear to me whether the traffic loads referred to by Mr. Lee as alarming "old-fashioned men" are those given for manual or for machine-switching equipments. In making the comparison of semi-automatic with manual loads, low handling times and high loads have been selected from available traffic data as near to the extreme experi[illegible] as seemed reasonable, in order [illegible]g might not be unduly favoured. [illegible] traffic [illegible] in the paper as presenting probably [illegible] manual service. I may note, [illegible] is purely local, and has zero not 100 per cent trunk traffic. The loads for semi-automatic operators on the contrary have been chosen from a great quantity of data with care to eliminate imperfectly supported claims as well as observed loads which are extreme though well established. For the semi-automatic system with manual answering the handling time is equated to flat rate calls and is the result of 3,890 observations by trained and disinterested traffic engineers. The handling time and observed load given for office F is the average of 5,455 observations of all calls as they occurred at the A positions, the records being made by automatic instruments which I have examined and believe to record correctly. The record of handling times and loads for office O was also of calls as they occurred and made by automatic instruments, and was checked under my supervision by trained observers. The loads for office P are equated to flat rate calls from automatic records covering all calls for one month, the equation taking account of single button calls to manual offices. The records of handling times for offices J and I were made by trained observers with stop watches and represent averages of particular tests of 100 calls as they occurred, confirmed by observations numbering 1,400 and 400 respectively. The observed operators' loads are read from automatic meters counting key-operations in continuous records which are available from the beginning of operation. As to the effect on the timed distribution of calls which are irregular or require exceptional attention, it should be explained that under normal loads and chance distribution the percentage of first waiting calls is not large relatively to the calls reaching an operator, while the percentage of second and third waiting calls is very small. Thus unless the calls requiring exceptionally long handling time should be much more frequent than is commonly observed, the disturbance of the timing arrangement to the disadvantage of waiting subscribers would be slight. Table D below shows the handling times measured from answering the call to pressing the last button in 605 observations of calls as they occurred.

TABLE D.

No.	Office	[illegible]	[illegible]	Maximum, Time sec.	Minimum, Time sec.
1	J	100	3·2	7·0	1·2
2	J	105	3·0	[illegible]	[illegible]
3	J	100	3·2	[illegible]	[illegible]
4	J	100	3·3	7·8	1·8
5	J	100	3·5	6·0	[illegible]
6	J	100	3·5	24·0	[illegible]

Although the average handling time has been obtained for a further large number of connections the observations were made with an integrating stop watch and no record was obtained of maximum and minimum. [illegible] of supervision by the telephone, both for recalls and other purposes in office J, the average duration of supervision was 3·25, the minimum 1·2, and the maximum 10·6. In office I the average handling time for calls to toll and information was 2·4 seconds, for the correction of errors [illegible] seconds, and for normal [illegible] seconds. The observations when compared with similar observations

Mr. McBerty.

at manual switchboards suggest that a result of brisk and businesslike attention and disposition of calls by the operator is a marked increase of briskness on the part of the subscriber.

Mr. Harrison observes that Fig. 1 shows little difference between 100-point and 200-point switches. It is to be noted that the crossing of the two curves at the 100 point is purely an accident. The chart indicates the numbers only of switches and terminals, and the difference is much more marked when the actual cost estimates are considered. The registers have not been counted in the equipment of machines. The difference in cost between 100-point and larger switches of types with which I am familiar is sufficient to cover the cost of registers with a considerable margin. The registers have, however, other valuable functions besides that of numerical translation to permit the use of large switches. Further, if desired, the advantages of large switches can be obtained in all selections excepting that of the wanted line without the aid of translating registers.

Mr. Hedley's remarks cover in a definite way the question raised by Mr. Harrison. Mr. Hedley's observation that the reduction in duration of connection which results from machine switching increases the probability of successful connection concurs with the general experience; in office I, for example, the duration of connection in semi-automatic equipment was about half that observed in the manual equipment which it replaced, and leaves such a surplus of machines that under normal conditions no call is blocked or delayed by trunks busy.

In answer to the question by Mr. Pook in respect of the significance in terms of first cost of Fig. 9, the cost of the machine-switching portions of the equipment is nearly proportional to the numbers. The cost of a complete working equipment is, however, modified by the addition of several elements which are not proportional to traffic, namely, power plant, line and cut off relays, meters, desks and manual toll switching equipment. I have no doubt that the proposed multiple overflow arrangement for busy hours could be operated, but I am inclined to think that a form of mechanical overflow would probably prove more economical. The suggestion that records be kept of peak loads of traffic at the different points in the system where calls are choked, is quite practical and has found application in a few exchanges with excellent results. It appears probable that automatic exchanges will be equipped in advance with recording mechanism for automatically recording traffic conditions at different points in the system.

BIRMINGHAM LOCAL SECTION, 28 MARCH, 1917.

Mr. Plummer.

Mr. T. **PLUMMER**: The question of automatic telephones has received much consideration in recent years, and the Post Office, in order to test the rival claims of various systems, has had machine-switching telephone gears installed by different contractors at several towns throughout the country, totalling about 16 in all. Careful records are being kept of the costs of capital and maintenance, as well as of the defects of the different systems and the faults to which they give rise, so that in the course of the next year or two full information on these most important matters will have been secured by the Telephone Administration. Apart from the question of economy in the employment of operators, the great improvement in machine switching is in my opinion the substitution of rigid electrical and mechanical contacts and gears for the flexible switching cords ordinarily used on manual boards. Telephone men know what a very large percentage of complaints of unsatisfactory working are due solely to defective cords, and no matter how frequently tested and rapidly thrown out of use, the flexible cords remain the essentially weak feature in the manual switchboard. The reduction in the employment of operators brought about by the installation of machine switching has a most important bearing on the question of building costs, as the smaller number of operators means a very large saving in exchange buildings, not only on account of the comparatively small floor-space occupied by the machine-switching gear, but also the saving in retiring rooms, dining rooms, etc., for the operators. This saving has not been referred to in the paper. The automatic system has a further advantage in relieving the telephone service from the imputation—rarely deserved—of the delay in completing calls on the part of the operators. The subscriber makes his own call and knows that any following delay is entirely due to the person called not attending promptly to the telephone. The arrangements for machine switching have been worked out to give practically an identical service to that with the manual board, the only difference being in relation to the need for the handling of traffic by operators on a manual board in connection with certain differential rates for the use of junctions and the trunk service. Self-contained towns seem to me to give the best results in the economy of operating staff which is brought about by the absence of junction circuits to other exchanges, unlike an area served by multi-exchanges. The system should also be useful for providing exchange services at villages with a couple of junctions to the nearest large town. Such facilities at present are greatly handicapped by the relative high costs of night and Sunday attendances for operators. Some installations of this description are now under trial by the Post Office. The semi-automatic system for the distribution of all incoming traffic amongst operators on a central battery manual switchboard has also been introduced at the Paddington Exchange, London, and is, I believe, giving entirely satisfactory results. I agree with the author in his conclusions on page 290 as to the maintenance of machine switching. Our experience is that the type of skilled men employed in dealing with the maintenance of ordinary common battery exchanges of the larger type are fully capable of handling automatic exchanges, and there is no need for the special training of such men in workshops where the manufacture and assembly of the apparatus takes place. The figures relating to the maintenance man-hours seem rather low; the author has explained that they refer to the moving switches only. Locally, such low figures have not been reached. In automatic working certain moving parts, as well as power plant, etc., have to be provided and maintained irrespective of the number of exchange lines actually connected, and in many instances additional subscribers' [illegible] appreciably increasing [illegible] charges of the plant. Another point concerning maintenance [illegible] automatic exchanges are installed [illegible] expected as a certain number [illegible] in excess of the actual requirements [illegible] emergency through sickness, etc. This factor will disappear as the type of exchange becomes more general, and a margin of trained staff will then be available for emergencies.

Mr. R. G. MASAROON: I have observed one feature in working an automatic telephone exchange to which there is no allusion in the paper, nor indeed in any literature which I have seen on the subject. It is that the subscriber is given something to do in getting his call through. I think that inventors in the past have been too leniently disposed towards the subscriber by relieving him of the necessity of doing anything except to lift the telephone from its rest and to speak. It is notorious that after a change-over from a magneto system to central battery working, subscribers frequently complain of the delay in answering calls, although the service under the new conditions is superior to what it has been under the old, i.e. the answering time is less. This has proved to be due to the [illegible] having nothing to do but wait after putting the telephone to his ear, whereas in a magneto system there is a handle to turn, and the time passes more quickly. I am glad to see that the tendency of invention is now in the other direction, and I look forward to the time when all exchanges will be automatic and the subscriber in making a call from, say, Exeter to Dundee will operate dials controlling the mechanism at intermediate points, say, Bristol, Birmingham, Leeds, and Edinburgh, and thus set up the circuit for himself. I should like to ask the author whether any means has been devised for redistributing the lines for outgoing traffic. Any redistribution which necessitates changing subscribers' numbers is out of the question, and the rigidity of the automatic system in this respect appears likely to be the cause of difficulties in adjusting traffic to meet abnormal conditions.

Mr. W. C. BURBRIDGE: With reference to the author's [illegible] the penultimate paragraph on page 288, I would emphasize the saving in the comparatively heavy conduit and cable cost which would ensue from the placing of small automatic units requiring only occasional attention [illegible] central automatic exchange by a limited number of trunks. Can the author say whether the United States administra[illegible] their longer experience of automatic plant, have [illegible]

Mr. F. R. McBERTY (*in reply*): Mr. Plummer refers to the saving in cost of exchange buildings which results from reducing the number of operators and the special [illegible] to in the paper for the reason that no direct comparisons [illegible] machine-switching equipments shops of substantial dimensions for repair work have been installed, which somewhat reduce the saving in space. Such shops now are seen to be unnecessary. In my experience no case has arisen in which the machine-switching equipment required as much space as a manual equipment of equal capacity; in general the service for an equal number of lines requires floor-space equal to two-thirds of that for a manual equipment. An important advantage of machine-switches is that of distributing the machinery into rooms of any form or arrangement in plan or in elevation in a way impossible with manual multiple boards, permitting a highly economical utilisation of the available space. As to Mr. Plummer's reference to the number of man-hours required for the maintenance of the local exchange (Dudley, in operation 9th September, 1916) the record of maintenance labour is at hand for the first four months only, during which time the average man-hours per line estimated for the year would amount to 24·7. During the period in question the exchange had 320 lines in operation, a calling rate of about 16 per line per day, with "in" and "out" toll traffic amounting to about 8 calls per line per day. The toll traffic was served by a six-position manual board. The estimated man-hours cover both the machine-switching equipment and the manual portions of the equipment, but exclude the time of wire chief and the supervision.

The observation of Mr. Masaroon that the operation of the full automatic dial gives the subscriber something to do and produces on him the impression that he is obtaining prompt service touches a peculiarity of the user which manifested itself at the adoption of the central battery automatic signalling equipment, and in a few cases led to the provision of an artificial means of occupying the attention of the subscriber, such as the turning of the handle of a magneto. The fact emphasizes the desire to avoid waste of time—a desire which can be met in machine-switching systems by further development in the direction of eliminating mechanical delays. The question as to means for redistributing lines for outgoing traffic has received an answer by Mr. Laidlaw, whose description and illustration of the by-path system will be found on page 295.

Mr. Burbridge asks whether experiments have been made in the United States in the saving of conduit and cable by placing small automatic units in suburban areas. Such equipments have been constructed at a number of places in the United States, notably at San Francisco, California, and Columbus, Ohio, although, so far as I am aware, no equipment has been planned for the maximum economy of underground plant. In thinly settled areas the maximum economy can be obtained only by the use of small units; the limit to the diminution of the size of the unit has been the high cost of housing and maintenance rather than the first cost of mechanism. With the progressive improvement of machine-switching units such a reduction of cost of maintenance and housing, with elimination of apparatus for keeping the switching equipment clean, dry, and warm, is to be expected as will permit the planning of equipments for extensive areas with a view to balancing first cost of wire and conduit against first cost of the switching mechanism as a main rather than a subordinate factor in annual charge.

THE DETERMINATION OF THE SEQUENCE OF PHASES FROM WATTMETER READINGS.

By Dr. GISBERT KAPP, Past-President.

(*Paper received 13 March, 1917.*)

The so-called "two wattmeter method" of measuring the power flowing through a three-phase line may be used to determine the power factor according to the well-known formula

$$\cos\phi = \tfrac{1}{2}\frac{1+r}{\sqrt{(1-r+r^2)}}$$

where r is the ratio between the two readings. This ratio has to be determined by dividing the smaller reading by the larger, and the power factor may then be read off from a chart such as is used in every test-room. The same chart may be used if the two readings are obtained by the well-known modification of the "two wattmeter method" where both readings are taken on the same wattmeter by using a change-over switch for the pressure circuit of the wattmeter.

The chart tells us what the power factor is, but nothing more. It does not tell us whether the current is leading or lagging nor the sequence of phases. This can only be found if we know, not only the ratio of the two readings, but also their signs as determined by the sequence of phases. Before we can tell whether any particular power factor read off on the chart means a lagging or a leading current, we must know the sequence in which the phases follow each other. When the generator is close at hand it is possible—though it may not be very convenient—to trace back the circuit to the generator and by observing the direction in which the generator is driven to establish the sequence of phases. Let us label the three terminals A, B, and C, then the current (or the electromotive force) in each will attain its positive crest value 120 time degrees after the other. Thus B may attain its positive crest value (or any particular phase condition) 120° after A or C has attained the same condition. In the former case we have the sequence A–B–C and in the latter the sequence C–B–A.

By tracing back the circuit to the generator it is therefore possible to interpret the chart reading as regards the sign of the phase angle: positive for a lagging and negative for a leading current. But it is not always convenient, and is frequently impossible, to trace the circuit back from the point where the power measurement is made to the generator. There may be a distance of miles between the two points and there may be various transformations within that distance. In such cases some other method purely local must be employed.

One obvious method is to insert a little inductance into the main lines and repeat the power measurement. If the power factor is then smaller than without the artificial inductances, the current is normally lagging; if greater, it is normally leading. Such a device is, however, costly, because the inductances must carry the main current and must be rather heavy pieces of apparatus. Their insertion means at least a temporary interruption of the supply, and, even after they have been inserted, some alteration and disturbance in the regular condition of the supply of power to the load. For these reasons we may dismiss this expedient as clumsy and often impracticable.

The following method is, however, quite practicable; it does not interfere with the power supply to the load, and the additional cost is confined to the provision of a paper condenser of a few microfarads capacity. The arrangement of apparatus is shown in Fig. 1. W is the wattmeter as ordinarily used, S is the change-over switch, also as ordinarily used, and K is a condenser which can be short-circuited by inserting the plug G. When the plug is inserted the sum of the wattmeter readings gives in the usual way the total power. If the plug is withdrawn the condenser is in series with the pressure coil of the wattmeter and the current through this coil is slightly advanced as compared with the usual test. The two readings will therefore be different from those obtained with the condenser short-circuited, and by analysing the two sets of readings it is possible to determine whether the sequence of phases is A–B–C or C–B–A, and also whether the current supplied to the load is lagging or leading.

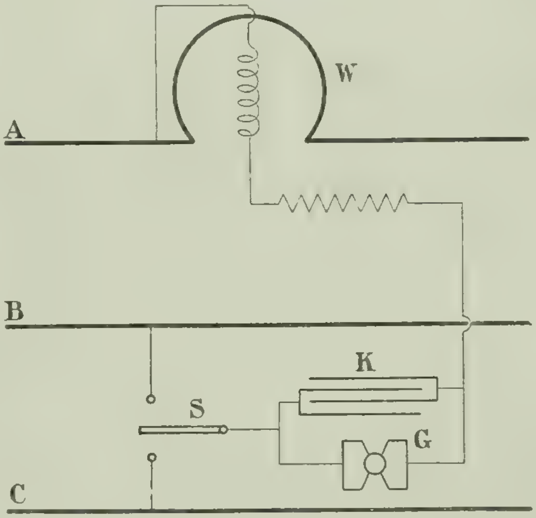

FIG. 1.

Fig. 2 shows the vector diagram for sequence A–B–C and a lagging current. AC and AB are the E.M.F. vectors of the pressure coil if the switch is connected to C and B respectively. The wattmeter readings are respectively P_c and P_b and are proportional to the projections of

[illegible]

$$\tan \gamma = [illegible]$$

[illegible]

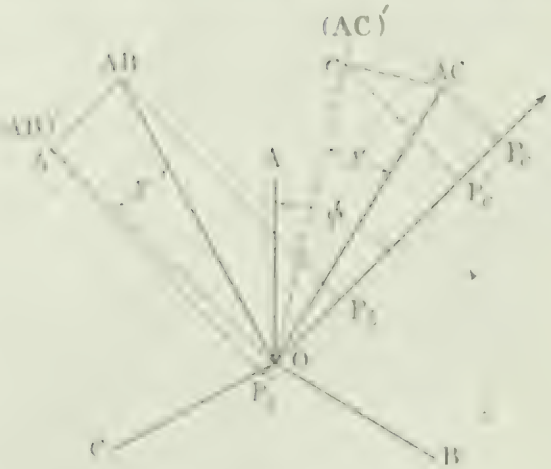

FIG. 2.

[illegible] to γ need not be known, but for greatest accuracy it [illegible]

$$[illegible]$$

The new readings will now be reduced, first because of the greater angle between the current and pressure vectors, and secondly because the current in the pressure coil has been reduced in the ratio of 1 to cos γ. The [illegible] P_b, and this is a criterion for the conditions to which the [illegible] current.

In the same way we can analyse the three other possible conditions, namely sequence A-B-C and leading current; sequence C-B-A and lagging current; and finally sequence C-B-A and leading current. It is unnecessary to demonstrate these different conditions in detail, as it would merely be a repetition of the above reasoning. It will suffice to give the result in tabular form.

[illegible] usual way give	...	$P_a > P_b$		$P_b > P_c$
If readings taken with [illegible]	[illegible]	[illegible]	[illegible]	P_a, $P > P$
Then sequence is	... A-B-C	C-B-A	A-B-C	C-B-A
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

In using this table, care must be taken to insert the powers with their proper sign; thus if P_b is numerically smaller than P_b', but the latter is negative whilst P_b is [illegible] than P_b.

[illegible] made by two wattmeters in the usual way. In this case the free terminals of the pressure coils must be connected through condenser and plug to the phase line labelled A, and the wattmeter must be inserted into the phase lines labelled B and C.

REPORT OF THE COUNCIL FOR PRESENTATION AT THE ANNUAL GENERAL MEETING OF 17 MAY, 1917.

At this, the Forty-fifth Annual General Meeting of The Institution of Electrical Engineers, the Council present to the members their Report for the year 1916–17.

Membership of the Institution.

The changes in the membership since the 1st April, 1916, are shown in the following table :—

	Hon. Mem.	Mem.	Assoc. Mem.	Assoc.	Grad.	Stud.	Totals
Totals at 1 April, 1916	7	1,500	3,466	520	382	801	6,676
Additions during the year :—							
Elected	..	6	103	..	47	107	263
Reinstated	..	1	1	1	..	1	4
Transferred to	1	35	110	1	32	..	179
Total	1	42	214	2	79	108	446
Deductions during the year :—							
Deceased	..	17	37	4	3	22	83
Resigned	..	9	27	14	2	9	61
Lapsed (Estimated)	..	32	56	18	10	70	186
Transferred from	..	1	32	5	45	96	179
Total	..	59	152	41	60	197	509
Net Decrease ...							63
Totals at 1 April, 1917 :—	8	1,483	3,528	481	401	712	6,613

In addition, 26 candidates for Associate Membership have been approved by the Council during the year for admission to that class on condition that they pass the Institution examination or otherwise satisfy the examination regulations. Of these, 11 are Graduates, 3 Students, and 12 non-members.

On the 15th June last, the following addition to the Articles of Association was adopted at a Special General Meeting of Corporate Members :—

"On and after the 15th day of June 1916 no person, whether a naturalized British subject or not, who is or shall be or has or shall have ever been a subject of a Country or State, then or thereafter at War with His Majesty or his successors, shall be or continue to be or be eligible for election as a member of any class of the Institution, provided nevertheless that the above disability shall not apply to a person who having at any time been a subject of such a Country or State as aforesaid shall have become and shall be a naturalized British subject and shall prove to the satisfaction of the Council that under the laws of such Country or State he has ceased to be and is not a subject thereof."

A searching investigation was made by the Council to ascertain the names of those who ceased to be members under the new clause and the total number affected was found to be 41 (39 Austrians, or Germans, and 2 Turkish subjects), all of whom have been removed from the List of Members.

Honorary Member.

The Council have pleasure in recording the announcement made at the Ordinary Meeting of the 26th October last that they had elected Professor G. Carey Foster, LL.D., D.Sc., F.R.S., Past-President (1881), to be an Honorary Member of the Institution.

Honours Conferred.

His Majesty the King has conferred the Grand Cross of the Order of the Bath upon the Right Hon. Sir J. H. A. Macdonald, K.C.B., LL.D., F.R.S., Member.

Military distinctions arising out of the War have been awarded during the year as follows :—

Distinction	No. of Awards
G.C.B. ...	1
C.B. ...	2
C.M.G. ...	3
D.S.O. ...	11
Bar to Military Cross ...	1
Military Cross ...	29
Distinguished Service Cross ...	1
Distinguished Conduct Medal ...	3
Military Medal ...	1
French and Russian decorations ...	6
Mentioned in despatches ...	71
Mentioned ...	37

The complete lists of names have been published in the *Journal* (vol. 54, p. 674, and vol. 55, pp. 56, 193, and 325).

Roll of Honour.

Thirty-nine members have been reported during the year to have lost their lives in the service of their country, and their names, together with their military ranks and the names of their Corps, are set out in the *Journal* (vol. 54, p. 674, and vol. 55, pp. 55, 193, and 325).

Other Members Deceased.

It is with the deepest regret that the Council have to record the death of Dr. Silvanus P. Thompson, Past-President.

[illegible] Dobson (Member of Council, 1902–[illegible]

[illegible] following members have died during the year :—

Members.

Bile, Harald.	Preece, John Richard, C.M.G.
Dobson, Sydney.	Rennie, John.
Ellis, William, F.R.S.	Scott, John Gray.
[illegible]	[illegible] K.C.M.G.
[illegible]	Stanley, William, Junr.
[illegible]	Stone, Henry Bernard.
[illegible]	

[illegible]

Austin, James M.	McCoull, Cecil.
Brown, Frank Blake.	Mann, John James.
[illegible]	Martin, Arthur William.
	Shephard, Dennis G.
Cornish, Vernon Keble.	Skerritt, John.
[illegible]	Southall, Arnold.
[illegible]	Stewart, John Erskine M.
[illegible]	Thornton, Edwin.
Luttrel-Elward, Henry.	Walton, William A.

Warde, Henry Wilder.

[illegible]

[illegible]	Franklin, Sir George.
Church, William.	Holmes, Philip.

[illegible]

Covell, Charles Edward.

[illegible]

[illegible]	[illegible] G.

MEETINGS AND PAPERS.

[illegible] the [illegible]

[illegible]	[illegible]
[illegible]	[illegible]
Electricity Supply	6
[illegible]	[illegible]
Finance	12
Membership	7
Papers	9
Research (including Sub-Committees)	24
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Wiring Rules (including Sub-Committee)	7
[illegible]	[illegible]
	[illegible]

There have been 42 meetings of Local Sections, viz.

Birmingham	6
Dublin	[illegible]
Manchester	[illegible]
Newcastle	7
[illegible]	6
Western	[illegible]
[illegible]	6
	42

Meetings have also been held by the Hong-Kong Local Centre.

The following is a list of papers read during the Session 1916–17, in addition to which 6 papers not read at meetings were accepted for publication in the *Journal* :—

Papers read at Meetings.

[illegible]	*Title.*
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
G. A. JUHLIN, Member.	[illegible] verters."
F. R. McBERTY, Member.	[illegible]
[illegible] Member.	[illegible]
[illegible]	[illegible]
J. S. PECK, Member.	"The parallel operation of electric [illegible]
[illegible] Member.	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	"[illegible] sion lines."
[illegible]	[illegible]
[illegible]	"[illegible] phones."

Papers accepted for publication in the Journal.

Author.	*Title.*
F. Creedy, Associate Member.	“Electric wave phenomena in the dynamo-electric machine.”
B. Hague.	“The mathematical treatment of the magnetomotive force of armature windings.”
G. Kapp, Past-President.	“The determination of the sequence of phases from wattmeter readings.”
A. E. Moore, Associate Member.	“A new concentric standard dynamometer wattmeter for heavy currents: and concentric non-inductive standards of low resistance.”
J. Orchiston, Member.	“Telegraph poles in New Zealand.”
S. P. Smith, D.Sc., Associate Member.	“The theory of polyphase armature windings.”

KELVIN LECTURE.

The eighth Kelvin Lecture was delivered by Dr. Alexander Russell, Vice-President, on the 9th November, 1916, the subject of the lecture being: “Some aspects of Lord Kelvin's Life and Work.”

PREMIUMS.

The following premiums for papers have been awarded by the Council:—

The Ayrton Premium (value £10).

G. V. Twiss.	“High-tension overhead transmission lines.”

The Fahie Premium (value £10).

F. R. McBerty.	“Machine - switching telephone gear.”

The Paris Premium (value £10).

C. Vernier.	“Wayleaves.”

An Extra Premium (value £10).

F. Gill and W. W. Cook.	“Principles involved in computing the depreciation of plant.”

An Extra Premium (value £10).

S. P. Smith, D.Sc.	“The theory of polyphase armature windings.”

In view of the small number of papers read this Session at meetings of the Students' Sections, no Students' premiums have been awarded, but the papers read will be taken into consideration at the next award of Students' premiums.

STUDENTS' SECTIONS.

Six meetings of the Students' Section have been held, at which papers were read and discussed. At the opening meeting an address to the Students was delivered by Dr. C. V. Drysdale, on “Post-War Electrotechnics” (see *Journal*, vol. 55, p. 187).

The Manchester Students' Section has held seven meetings.

No meetings of the Newcastle and Scottish Students' Sections have been held.

SCHOLARSHIPS.

In view of the absence of a large number of Students on Naval or Military Service, the Council have decided not to award the David Hughes and the Salomons Scholarships this year.

MEETINGS OF OTHER SOCIETIES.

In addition to the Incorporated Municipal Electrical Association, who held their Summer Meeting at the Institution, 18 Societies and various Committees have held meetings at the Institution during the year, as follows:—

	No. of meetings
Associated Municipal Electrical Engineers of Greater London	13
Electrical Trades' Benevolent Institution ...	2
Incorporated Municipal Electrical Association	10
Institution of Post Office Electrical Engineers	11
Institution of Railway Signal Engineers ...	5
Post Office Telephone and Telegraph Society	[illegible]
Röntgen Society	8
University of London Board of Studies in Electrical Engineering	4
Eleven other Societies and Linking-up Committees	45
	113

ANNUAL DINNER AND ANNUAL CONVERSAZIONE.

On account of the War these functions have not been held.

PROXY VOTING.

In order to give facilities for voting by those not present at meetings, the Council will at an early date place proposals before the members with a view to altering the Articles of Association so as to provide for Proxy Voting at the Annual and Special General Meetings of the Institution, in the form ordinarily adopted by Public Companies.

LOCAL HONORARY SECRETARY AND TREASURER ABROAD.

The Council have appointed Mr. J. E. Donoghue to be Local Honorary Secretary and Treasurer of the Institution for New South Wales, in succession to Mr. J. Y. Nelson. The Institution is indebted to Mr. Nelson for his valuable services in promoting its interests.

“SCIENCE ABSTRACTS.”

The number of articles to be dealt with in “Science Abstracts” was less than normal, in view of the interruption of scientific work through the War. The volumes contained 984 pages, as against 1,264 in 1915. The net cost of the publication to the Institution was £291, as compared with £549 in 1915.

WIRING RULES.

Since the publication of the Seventh Edition of the Wiring Rules in March 1916, a number of suggested alterations have been submitted for the consideration of the Committee. It is not proposed, however, to undertake a further general revision of the Rules until after the War.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

C. H. Wordingham (*Chairman*).

[illegible]

[illegible]

J. W. Kempster. S. G. C. Russell.

[illegible]

[illegible]	[illegible]
[illegible]	Lloyd's Register of Shipping.
J. T. Milton	
[illegible]	British Electrical and Allied Manufacturers' Association.
T. Carlton	Board of Trade.
[illegible]	Electrical Contractors' Association.
J. Foster King	British Corporation for the Survey and Registry of Shipping.
[illegible]	Institution of Engineers and Shipbuilders in Scotland.
[illegible]	Institution of Naval Architects.
[illegible]	[illegible]

[illegible] be published in the course of the next few [illegible] will prove of value to [illegible]

[illegible]

The Standard Specification for Street Lighting prepared by the Special Committee appointed for this purpose will be published in the *Journal* at an early date as a [illegible]

[illegible]

On account of the War, no examinations have been held.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] respect of which application has been made to the Research Department for £500, and an appeal for contributions [illegible] Supply Undertakings, several of whom have already aided the research by the loan of cables and the granting of facilities for experiments.

[illegible]

Specimens of 10 different brands of Insulating Oils have been distributed among 6 investigators who are carrying out tests 1 to 7 from the following list, and as many of the others as they can arrange for :—

(1) Tendency to sludge.
(2) Loss by evaporation.
(3) Flash point.
(4) Viscosity at different temperatures.
(5) Chemical reactions.
(6) Density and coefficient of expansion.
(7) Cold test (solidification).
(8) Moisture absorption.
(9) Dielectric strength.
(10) Specific resistance.
(11) Thermal transference.
(12) Specific heat.

The expenditure on the research for 1916 was £356, of which £250 was provided out of a grant made by the Research Department.

The expenditure for 1917 is estimated at £810 (which includes £60, value of oils supplied free of charge by various makers) towards which application has been made to the Research Department for a grant of £670, leaving the Institution to provide the balance.

[illegible]

Panel Committees have been appointed by the Council to formulate schemes of research on various Insulating Materials, with a view to drawing up standard specifications for the purchase of such materials and for discriminating between the various grades. The following materials are included in the research :—Porcelain, ebonite, mica, micanite, fibrous materials, insulating varnishes, and composite materials. Application has been made to the Research Department for grants in aid of these Researches. The proposed schemes of research have already been drawn up in the case of most of the materials.

It has been agreed between the Institution and the British Electrical and Allied Manufacturers' Association to co-operate in this research, and, with a view to ensuring that the two researches should not overlap but mutually assist one another, the Institution will deal mainly with the scientific part of these researches, and the Association with the industrial. Each body will have representatives on the Committees of the other dealing with this research.

ELECTRICITY SUPPLY.

In October 1916 the Council appointed a Committee consisting of

[illegible]

C. H. Merz. T. Roles.
G. W. Partridge. C. P. Sparks.
S. L. Pearce. W. B. Woodhouse.

with the following reference:—

> "To report to the Council on the best means of co-ordinating and improving Electricity Supply in the United Kingdom."

Six meetings have been held. The Committee have been in close touch with the National Electric Supply Joint Committee appointed by the Incorporated Municipal Electrical Association and the Incorporated Association of Electric Power Companies, and, in order to prevent overlapping, it has been agreed that the Institution Committee will devote its attention to the question of electricity supply from the point of view of the requirements of the country as a whole, and will deal with the engineering aspect of the matter, while the Joint Committee will go into more immediate questions of organization and linking-up of existing undertakings, etc.

The following matters, amongst others, are engaging the attention of the Committee:—

1. A standard frequency for the country.
2. The voltages that should be recommended for transmission and distribution purposes.
3. The obtaining of reasonable facilities for way-leaves.

The Committee have already arrived at a decision as regards standard frequencies for certain large areas in the country, but they feel that it is not advisable to put forward their recommendations piecemeal.

They have been awaiting the publication of the report of the Electrical Trades Committee of the Board of Trade, in order that they might work as far as possible along the lines which it was anticipated would be indicated therein. It is uncertain when the report of this Committee will be published, especially in view of the recent appointment of an Electric Power Supply Committee by the Board of Trade, with a reference generally similar to that of the Institution Committee.

The Committee will, however, proceed with their deliberations in the hope that their recommendations will enable the Institution to render some effective assistance to the Board of Trade Committee.

The questions referred to above require careful consideration, and it is therefore probable that some time will elapse before definite recommendations can be made upon them.

ELECTRICAL TRADES COMMITTEE OF THE BOARD OF TRADE.

The President gave evidence before this Committee in May 1916, and the recommendations made by him on behalf of the Council have already been published in the *Journal* (vol. 54, p. 673).

ENGINEERING STANDARDS COMMITTEE.

In response to an appeal from the Committee, the Council have made a grant of £500 towards the expenses of its Translations and Foreign Local Committees Guarantee Fund, in addition to a grant of £50 for current expenditure.

NATIONAL SERVICE.

Members on Naval or Military Service.

From returns supplied by members it appears that the number of members serving or having served in the Navy or the Army since the outbreak of the War is 1,671, namely, 163 Members, 764 Associate Members, 83 Associates, 127 Graduates, and 534 Students.

A Greetings Card was sent last Christmas in the name of the Institution to its members on active service.

Commissions.

During the course of 1916 the President, at the request of the Authorities, nominated a limited number of electrical engineers for commissions as Lieutenants, R.N.V.R., for electrical duties on board H.M. battleships, and as Equipment Officers, Royal Flying Corps.

Employment of Disabled Sailors and Soldiers.

Classes have been in progress at the Northampton Polytechnic Institute, Clerkenwell, E.C., since June 1916, for giving a preliminary training to Disabled Sailors and Soldiers with a view to their being employed as Electricity Substation Attendants.

Of 111 men who commenced the first six courses 96 were approved for employment and 91 actually placed. Nineteen other men have just completed their course. The total number of applications received from employers was over 230.

The Committees of the Local Sections are co-operating in regard to extending the scheme to towns other than London, and a first batch of men is under instruction at Manchester, while considerable progress has been made with schemes for Birmingham, Leeds, and Newcastle.

The Council have also received a letter from the Ministry of Labour inviting the co-operation of the Institution in carrying out an investigation in regard to openings in the Electrical Engineering Industry for Disabled Sailors and Soldiers, including the question of preliminary training. The Council have appointed a special committee to deal with this matter, and enquiries are being made from members connected with representative firms and undertakings in the Industry.

Institution Premises.

In addition to the first floor rooms, which have been in the occupation of Departments of the Government almost continuously since the beginning of the War, the portion of the Institution building occupied by the Institution has recently been taken over by the Authorities, and temporary offices have been found for the Institution at No. 1, Albemarle Street, W. 1. H.M. Office of Works have agreed to pay a rental to the Institution for the use of its premises.

Until further notice, the meetings will be held at the Institution of Civil Engineers, by whose kind hospitality the necessary facilities for this purpose have been granted.

Reserved Occupations Committee.

At the beginning of February the attention of the Council was drawn to a Memorandum issued by the Reserved Occupations Committee in regard to substitution in Electrical Generating Stations and to a statement by [illegible] be continued without modification after the end of that month.

In view of the risk to the nation which would be in- [illegible] f Electric Power Companies, the Conference of Chief Officials of the London Electric Supply Companies, and the Provincial Electric Supply Committee of Great [illegible] labour employed by Electricity Supply Undertakings in proportion to the number of employees working in factories depending upon electric power supplied by such Undertakings, and (b) the fuel economy effected through [illegible] views, in the course of which the Chairman of the Com- [illegible] have done all that was possible, the wish of the Committee [illegible] classes in addition to those mentioned in its Memorandum [illegible] time to show what further substitution has taken place. This matter is having the further careful consideration of [illegible]

Coal Supplies.

During the first half of 1916, representatives appointed by the Councils of the Institution and of the Institution of [illegible] steps to [illegible] and electricity under- [illegible] being given to these Public Utility Undertakings.

[illegible]

[illegible]

[illegible]

The Accounts of the Fund, which are separate from [illegible]

[illegible]

[illegible] to the credit of the General Fund, compares with [illegible] 7d.

[illegible]

	£	s.	d.
In the Accounts for 1915 these stood at	33,491	5	4
Amount of repayment during the year	772	0	6
[illegible]	[illegible]	[illegible]	[illegible]

Life Compositions Fund.—The total of the Fund on the 1st January, 1916, was £5,300 19s. and a further amount of £16 16s. was received in payment of Life Compositions during the year, a total of £5,317 15s. Out of this the sum of £61 has been transferred to the General Fund, in accordance with the Articles of Association, on account of Life Compositions of members deceased during the year, leaving to the credit of the Fund £5,256 15s.

[illegible]

	£	s.	d.
Donations, Subscriptions, etc.	[illegible]	[illegible]	[illegible]
Contribution out of Institution [illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]

which amount was applied in reduction of the Economic [illegible] Investments at cost, and the Institution Building and Lease, the Library and Furniture, etc., at the values [illegible]

	£	s.	d.
the Assets amount to	[illegible]	[illegible]	[illegible]
against Liabilities	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

which is made up as follows :—

	£	s.	d.	£	s.	d.
Building Fund	[illegible]	[illegible]	[illegible]			
Life Compositions Fund ...	[illegible]	[illegible]	0			
Kelvin Lecture Fund	[illegible]	[illegible]	[illegible]			
Foreign Visit Fund	[illegible]	[illegible]	2			
Subscriptions received in [illegible]	[illegible]	[illegible]	[illegible]			
General Fund	[illegible]	[illegible]	[illegible]			
				[illegible]	[illegible]	[illegible]
This balance, in comparison with that of [illegible]				[illegible]	[illegible]	[illegible]
shows an improvement for 1916 of				[illegible]	[illegible]	[illegible]

War Loan.

Since the accounts for 1916 were closed, £5,250 of the [illegible] tion, and the existing holding of £661 2s. in the 4½ % Stock has been converted into 5 % [illegible]

Library.

[illegible] April 1916, and 78 books and pamphlets have been presented by members, non-members, and publishers.

The approximate number of volumes in the Institution and Ronalds Libraries is as follows :—

		Volumes
Institution Library (exclusive of Lending Library)		
Text-books, Treatises, etc. ...	4,293	
Periodicals, Transactions of Societies, etc.	5,481	
		9,774
Ronalds Library		1,800
		11,574

The total number of readers during the past twelve months was 1,305.

It is regretted that with the exception of a small number of works of reference and bound volumes of periodicals it has not been possible for reasons of space to transfer the Reference and Ronalds Libraries to the Institution's temporary offices, and they will therefore not be accessible for the present, with the exception indicated above.

The Library and Reading Rooms of the Institution of Civil Engineers have been kindly placed at the disposal of members while the Institution is in temporary premises.

During the year, 516 books were issued from the Lending Library to 240 borrowers, the corresponding numbers in the previous year being 530 and 208 respectively.

The Lending Library has been removed to the Institution's temporary offices, and continues to be available for the loan of books to members, who can obtain the same on application to the Secretary.

THOMPSON MEMORIAL LIBRARY.

The Council decided last year to set aside on behalf of the Institution the sum of £1,000 towards the setting-up of a memorial of the late Dr. Silvanus P. Thompson, and determined that in the event of the proposed purchase of his valuable collection of early and modern works on Electricity, Optics, and other branches of Physics, for the establishment of a Thompson Memorial at the Institution being effected, the above-mentioned sum should be contributed for that purpose.

It has since been decided to purchase the collection by means of subscriptions from members of the Institution and others with a view to its being presented to the Institution and preserved as a memorial of its distinguished Past-President, and the above contribution has been made by the Institution towards the purchase-money.

MUSEUM.

The following items are among the recent additions to the collection :—

Articles presented	Donor
A Frager meter	Corporation of Liverpool
Two framed photographs of telegraph insulators and 25 unmounted photographs illustrating the installation of telephones in London by the Post Office in 1901–2	Sir John Gavey, C.B.
Thirteen Lane Fox incandescent lamps made at Westminster in 1882	Westminster Engineering Co., Ltd., per J. O. Girdlestone
A piece of the first Atlantic cable	P. Peters
A piece of fused cable from one of the Rand mines	J. H. Rider
Seven X-ray tubes, mounted on black wooden stands (1896–7)	A. A. C. Swinton

THE INSTITUTION OF ELECTRICAL ENGINEERS

REVENUE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1916.

Dr. EXPENDITURE.

[illegible]		£ s. d.	£ s. d.
[illegible]	To Management:—		
	Salaries and Wages (including Staff [illegible] Account)	[illegible]	
	[illegible]	[illegible]	
	[illegible]	[illegible]	
	[illegible]	[illegible]	
	Stationery and Office Requisites	[illegible]	
	[illegible]	[illegible]	
	Postage of Correspondence and Notices	[illegible]	
	Telephones	[illegible]	
	Travelling Expenses	[illegible]	
	Bank Charges	[illegible]	
[illegible]			[illegible]
	Institution Buildings:—		
	Ground Rent	[illegible]	
	Rates and Taxes	[illegible]	
	Light and Power	[illegible]	
	Firing	[illegible]	
	Insurance	[illegible]	
	[illegible]	[illegible]	
	Household Requisites and Cleaning	[illegible]	
[illegible]			[illegible]
[illegible]	„ [illegible]		[illegible]
[illegible]	„ Furniture and Fittings (Repairs and Renewals)		[illegible]
	„ Journal:—		
	Printing	[illegible]	
	[illegible]	[illegible]	
	[illegible]	[illegible]	
		[illegible]	
	Less Sales	[illegible]	
[illegible]			[illegible]
[illegible]	„ [illegible]		[illegible]
[illegible]	„ [illegible]		[illegible]
[illegible]	„ [illegible]		[illegible]
	Carried forward		[illegible]

INCOME. Cr.

[illegible]		£ s. d.	£ s. d.
[illegible]	By Subscriptions		[illegible]
[illegible]	„ Entrance Fees		[illegible]
	„ [illegible]:—		
	[illegible]	[illegible]	
	[illegible]	[illegible]	
[illegible]			[illegible]
[illegible]	„ Dividends on Investments		[illegible]
[illegible]	„ Interest		[illegible]
[illegible]	„ [illegible]		[illegible]
[illegible]	„ [illegible]		[illegible]
	„ Institution Buildings:—		
[illegible]	[illegible]		[illegible]
	„ [illegible]:—		
	[illegible]	[illegible]	
	[illegible]	[illegible]	
[illegible]			[illegible]
	Carried forward		[illegible]

REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued.*

		£ s. d.	£ s. d.
	Brought Forward	...	... 12,208 10 8
	To NATIONAL SERVICE:—		
	Coal Supplies, Honours Lists, Greetings Card, Removal of Enemy Members, etc.	104 19 0	
	Allowances to Members of Staff on Military Service	340 15 10	
53 11 9			445 14 10
	„ SCIENCE ABSTRACTS :—		
	Salaries, Abstracting, Printing, Postage, etc....	1,749 12 6	
	Less Subscriptions, Sales, and Advertisements	1,458 2 3	
549 0 5			291 10 3
	„ MEETINGS :—		
	Advance Proofs	31 19 1	
	Reporting	59 17 0	
	Honoraria to Kelvin Lecturers	50 0 0	
	Refreshments, Assistance, etc.	59 9 8	
193 7 1			201 5 9
	„ LOCAL SECTIONS :—		
	Money Grants	631 13 4	
	Travelling Expenses	132 1 1	
832 11 6			763 14 5
110 10 1	„ PREMIUMS	... ...	72 9 9
50 0 0	„ ENGINEERING STANDARDS COMMITTEE ...	... ...	25 0 0
3 13 3	„ RESEARCH COMMITTEE	... ...	203 9 4
25 0 0	„ INTERNATIONAL ILLUMINATION COMMISSION	... ...	5 0 0
18 11 7	„ LEGAL EXPENSES	... ...	46 14 4
58 1 1	„ MISCELLANEOUS EXPENSES	... ...	56 14 9
	„ AMOUNTS TRANSFERRED TO :—		14,410 4 1
	BUILDING FUND (Obligatory repayment to Economic Life Assurance Society) :—		
	Donations, Subscriptions, etc. (*per contra*) ... £44 15 8		
	Contribution out of Revenue 727 4 10		
740 5 8		772 0 6	
277 12 2	SINKING FUND (Premiums for Redemption of Cost of Building and Lease) ...	277 12 2	
	GENERAL FUND :—		
	Expenditure on—		
79 18 3	Books and Binding for Library ...	72 15 5	
—	Furniture	25 0 0	
1,847 1 0	**Balance, being unexpended Revenue for the year 1916**	3,776 17 7	
			4,924 5 8
			£19,334 9 9

INCOME—*continued.* **Cr.**

	£ s. d.
Brought Forward	... 19,334 9 9
	£19,334 9 9

BALANCE SHEET, 31st DECEMBER, 1916.

Dr. LIABILITIES.

	£ s. d.	£ s. d.
To Building Fund:—		
Balance at 1st January, 1916	[illegible]	
Donations, Subscriptions	[illegible]	
Contributions out of Revenue	[illegible]	
		[illegible] 17 6
„ [illegible]:—		
[illegible]	[illegible]	
[illegible]	[illegible]	
	[illegible]	
On Mortgage of Tothill Street Buildings and Site [illegible]	[illegible]	
		[illegible]
„ Life Compositions Fund:—		
Balance at 1st January, 1916	[illegible]	
Life Compositions received	[illegible]	
	[illegible]	
Less Life Compositions of Deceased Members transferred to General Fund	[illegible]	
		[illegible]
„ Kelvin Lecture Fund:—		
As per last Balance Sheet		[illegible]
„ Trust Funds Capital Accounts:—		
Salomons Scholarship	[illegible]	
David Hughes Scholarship	[illegible]	
Wilde Benevolent Fund	[illegible]	
		[illegible] 4 9
„ Trust Funds Income Accounts:—		
Unexpended balances:—		
Salomons Scholarship	[illegible]	
David Hughes Scholarship	[illegible]	
Wilde Benevolent Fund	[illegible]	
		[illegible]
Accrued Interest (Wilde Benevolent Fund)		[illegible]
„ [illegible] Fund		[illegible]
„ Sundry Creditors		[illegible]
„ Subscriptions received in advance		[illegible]
Carried Forward		[illegible] 2 8

Cr. ASSETS.

	£ s. d.	£ s. d.
By Institution Buildings and Lease:—		
Cost	[illegible] 6 1[illegible]	
Less Reserve for Depreciation, being Sinking Fund Instalments paid	[illegible] 11 1[illegible]	
		[illegible] 1[illegible] 0
„ Sinking Fund Payments (paid for Redemption of Cost of Building and Lease)		2,[illegible] 11 1[illegible]
„ Tothill Street Buildings and Site (at cost)		19,26[illegible] 17 1
„ Life Compositions Investments (at cost)*:—		
£[illegible] New Zealand Railways 4% Debentures	2,[illegible]78 12 6	
£[illegible] Lancashire and Yorkshire Railway 4% Preference Stock	1,[illegible] 10 4	
£[illegible] Assam Bengal Railway 3% Stock	1,[illegible] [illegible] 6	
		5,332 2 10
„ Kelvin Lecture Fund Investment (at cost)*:—		
£[illegible] 4½% War Stock		64[illegible] 13 6
„ Trust Funds Investments (at cost)*:—		
Salomons Scholarship:—		
£[illegible] New South Wales 3½% Stock	1,[illegible] 5 9	
£[illegible] Cape of Good Hope 3½% Stock	[illegible] 13 6	
		2,129 19 3
David Hughes Scholarship:—		
£[illegible] [illegible] Railway 3% Guaranteed Debenture Stock	1,968 15 0	
Cash at Post Office Savings Bank	1 [illegible] 6	
		[illegible]
Wilde Benevolent Fund (Capital Account):—		
£[illegible] Great Eastern Railway Metropolitan 3% Guaranteed Stock	1,4[illegible]3 19 3	
£[illegible] [illegible] Railway 4% Guaranteed Stock	[illegible] 19 9	
£[illegible] London County 3½% Stock	1[illegible]1 8 6	
		1,[illegible] [illegible] 6
Wilde Benevolent Fund (Income Account):—		
£[illegible] New South Wales 4% Stock	2[illegible]1 6 [illegible]	
£[illegible] 4½% War Stock	94 8 8	
		3[illegible] 14 8
„ Library (portion of the Ronalds Library and Fund [illegible] not held in Trust):—		
As per last Balance Sheet	1,3[illegible] 15 9	
Additions (at cost)	72 15 5	
	1,[illegible] 11 2	
Less Depreciation (10%)	1[illegible] 17 1	
		1,258 14 1
Carried Forward		105,847 12 3

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.*

		£ s. d.	£ s. d.
Brought Forward			93,222 2 8
To Repairs Suspense Account :—			
Balance (as per last Balance Sheet)		70 14 10	
Amount set aside in 1916		400 0 0	
		470 14 10	
Less Expenditure on Repairs in 1916... ...		184 18 11	
			285 15 11
„ General Fund :—			
Balance at 1st January, 1916		23,619 1 1	
Life Compositions of Deceased Members ...		61 0 0	
Expenditure in 1916 on—			
Books and Binding for Library		72 15 5	
Furniture		25 0 0	
Unexpended Revenue for 1916		3,776 17 7	
		27,554 14 1	
Less Depreciation (*per contra*) :—			
Library	£139 17 1		
Furniture, Fittings, and Apparatus	124 4 5		
		264 1 6	
			27,290 12 7
			£120,798 11 2

J. E. KINGSBURY,
Honorary Treasurer.
P. F. ROWELL,
Secretary.

ASSETS—*continued.* **Cr.**

	£ s. d.	£ s. d.
Brought Forward		105,847 12 3
By Furniture, Fittings, and Apparatus :—		
As per last Balance Sheet	2,459 7 11	
Additions in 1916	25 0 0	
	2,484 7 11	
Less Depreciation (5 %)	124 4 5	
		2,360 3 6
„ Sundry Debtors		669 1 11
„ Insurance Premiums and Sundry Payments in Advance ...		275 18 5
„ Stock of Paper for Publications		733 18 9
„ General Fund Investments (at cost)* :—		
£750 Western Australia 4 % Stock	730 8 3	
£750 Union of South Africa 4 % Stock	742 12 0	
£750 Madras and Southern Mahratta Railway 4 % Debenture Stock	738 15 6	
£35 East Indian Railway "B" Annuity	791 5 4	
£1,500 South Australian 4% Stock	1,494 10 6	
		4,497 11 7
„ Cash :—		
Treasury Bills	4,933 13 6	
At Bankers'	1,473 0 10	
At Post Office Savings Bank (David Hughes Scholarship Trust Fund Uninvested Income)	0 0 9	
In hands of Secretary...	7 9 8	
		6,414 4 9
		£120,798 11 2

* The above values are subject to depreciation, but, in view of the continuance of the War, no estimate of present values can usefully be made.

We beg to report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1916, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of the Institution.

SIDNEY SHARP, *Honorary Auditor.*

ALLEN, ATTFIELD & CO., *Auditors,*
Chartered Accountants,
147, Leadenhall Street, E.C. 3.

13*th April*, 1917.

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.		Cr.	£ s. d.
[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]
	[illegible]			[illegible]

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.		Cr.	£ s. d.
[illegible]	[illegible]		[illegible]	[illegible]
			[illegible]	[illegible]
			[illegible]	[illegible]
	[illegible]			[illegible]

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£ s. d.		Cr.	£ s. d.
[illegible]	[illegible]		[illegible]	[illegible]
			[illegible]	[illegible]
			[illegible]	[illegible]
	[illegible]			[illegible]

RESEARCH ACCOUNT

Dr.	£ s. d.		Cr.	£ s. d.
[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]
			[illegible]	[illegible]
	[illegible]			[illegible]

THE BENEVOLENT FUND OF
THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1916.

Dr. EXPENDITURE.

	£	s.	d.
To Grants	195	0	0
,, Printing, Stationery, and Postage	3	7	0
,, Unexpended Balance carried to Balance Sheet	339	7	6
	£537	14	6

INCOME. **Cr.**

	£	s.	d.
By Dividends on Investments	182	0	10
,, Interest on Deposit	16	9	8
,, Annual Subscriptions	118	16	6
,, Donations of £5 and over	94	15	0
,, Donations under £5	25	12	6
,, Legacy from the late Mr. H. C. Donovan	100	0	0
	£537	14	6

BALANCE SHEET, 31ST DECEMBER, 1916.

Dr. LIABILITIES.

		£	s.	d.
To Capital (as per last Balance Sheet)		4,042	3	0
,, Income and Expenditure Account :—				
As per last Balance Sheet	£1,493 16 4			
Unexpended Balance in 1916	339 7 6			
		1,833	3	10
,, Sundry Creditors		31	19	3
		£5,907	6	1

ASSETS. **Cr.**

		£	s.	d.
By Investments (Capital), at cost :—				
£961 7s. 7d. Cape of Good Hope 3 % Stock		950	0	0
£593 1s. 7d. New South Wales 3 % Stock		600	0	0
£420 Great Eastern Railway 4 % Preference Stock		503	18	3
£600 North Staffordshire Railway 3 % Debenture Stock		551	0	9
£750 East Indian Railway 3½ % Debenture Stock		737	18	0
£300 London and North-Western Railway 4 % Guaranteed Stock		333	11	0
£500 New Zealand 3½ % Stock		480	18	0
£500 Canada 3½ % Stock		478	16	0
		4,042	3	0
,, Investments (Income), at cost :—				
£350 New South Wales 4 % Stock	£336 18 6			
£200 War Stock 3½ %	188 17 3			
£500 War Stock 4½ %	497 6 6			
		1,023	2	3
,, Sundry Debtors		130	0	0
,, Cash :—				
At Bankers'	£679 10 10			
In hand	32 10 0			
		712	0	10
		£5,907	6	1

We have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Bankers. The Investments, which are stated at cost, are subject to depreciation.

SIDNEY SHARP,
JAS. ATTFIELD, F.C.A. } *Honorary Auditors.*

25th April, 1917.

PROCEEDINGS OF THE INSTITUTION.

596th ORDINARY MEETING, 8 MARCH, 1917.

Mr. C. P. Sparks, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on the [illegible], 1917, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The PRESIDENT: I have to announce that the Institution of Civil Engineers has invited the members of this Institution to attend three Lectures to be given at Great George Street, Westminster (see page 240).

I have also to announce that in all probability H.M. Office of Works will shortly be taking over the Institution building to house a Government Department. In that event we shall try and make arrangements to hold meetings in some other building in London.

Messrs. C. P. Hammond and W. C. Clinton were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Member.

Digby, Thomas Joseph.

Associate Members.

[illegible]
Holt, Frank Bertram.
Knight, Berkeley.
Knowles, William Cordingley.
Moir, George Harris.
Parkinson, Walter.
[illegible]
Ridley, Horatio James W.
Wolton, Harry William.

Graduates.

Burgess, William.
Guilford, William Stephenson.
Muttannah, Kuppanda Muttannah.

Students.

Beak, Allan Llewellyn.
Berry, Herbert.
Dawson, Cecil.
Gough, William Eric.
Heymann, Paul Gerhard.
Liddiard, Hugh William Conway.
Payne, Eric Arthur.
Thomas, Alan Ormond.
Wilman, Charles Wilfrid.

TRANSFERS.

Associate Member to Member.

Jackson, Charles William.
McClelland, William.
Wright, Russell Stuart.

Graduate to Associate Member.

Phillips, Walter.

Student to Associate Member.

Chatten, Walter Henry.
Fisher, Robert Edward S.
Miley, Percy.
Ripley, Horace Stephens.
Smith, Sidney Bertram.
Tetlow, Herbert.

Student to Graduate.

Dent, Lancelot Brown.
Pemberton, Norman.
Thomas, Frederick.
Vick, Ernest Henry.

A paper by Mr. G. A. Juhlin, Member, entitled "Voltage Regulation of Rotary Converters" (see page 241), was read and discussed, and the meeting adjourned at 9.40 p.m.

597th ORDINARY MEETING, 22 MARCH, 1917.

Mr. C. P. Sparks, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on the 8th March, 1917, were taken as read, and were confirmed and signed.

The PRESIDENT: I announced at the last meeting that this building would be taken over at an early date by the Government. The actual date of the taking over has not yet been fixed, but we expect that it will be within a [illegible], and in all probability our next meeting will be held at the Institution of Civil Engineers. An announcement will be made in the [illegible], and notices will be sent to members as to the hour of the meeting.

[illegible] were appointed scrutineers of the ballot for the election and transfer of members, and at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Member.

[illegible] Alfred [illegible]glehurst.

Associate Members.

Baty, James Elphinstone.
Bedson, Noel Phillips.
Bolton, Charles Frederick.
Childs, Harold Borlase T.
Cook, Charles Percival.
Currie, Robert Thomas.
Hawkins, Frank James.
Highan, Harold.
Lever, Graham George.
Macdonogh, John Charles C.
Nottage, William Hockley.
Paterson, Quentin Hunter, Lieut. R.N.
Powell, Enoch Gwyn.
Welply, James Huston.
Wilson, Arthur Leslie.

Graduate.

Geary, Frederick Arthur.

Students.

Bernstein, Philip Leonard.
Bridge, Albert.
Bridgeman, Wilfrid Robert O.
Cooke, Harry Rowland.
dos Ramos, Herculano [illegible]
Habershon, Matthew Keith.
Holmes, Tom, Art. Corporal [illegible]
Janes, William Philpott.
Jennings, James Smith.
Morris, Arthur John.
Parkin, Willie.
Peskett, Ernest George A.
[illegible] Charles Frank.

TRANSFERS.

Associate Member to Member.

Belling, Charles Reginald.
Jones, Christopher.

Associate to Associate Member.

Morris, Robert F.

Graduate to Associate Member.

Bridger, William, B.Sc. (Eng.).
Cooke, Lionel Ernest.
Gow, Alexander George.

Student to Associate Member.

Curtis, Hugh Harry.
Gilbert, William.
Kettle, Arthur Stafford.
Taylor, Stanley Edward W., M.Sc. (Tech.).
Warren, Henry William H.

Student to Graduate.

Khan, Lutfe Ali.

A paper by Mr. F. R. McBerty, Member, entitled "Machine-switching Telephone Gear" (see page 265), was read and discussed, and the meeting adjourned at 10.5 p.m.

INSTITUTION NOTES.

TEMPORARY OFFICES.

The Institution premises having been taken over by H.M. Government, the temporary address of the Institution is now 1 Albemarle Street, London, W. 1.

The telephone number will be as before, viz. "Gerrard 764," and the telegraphic address will be "Voltampere, Piccy, London."

LIBRARY.

With the exception of a small number of works of reference and bound volumes of periodicals, it has not been possible for reasons of space to transfer the Reference and Ronald's Libraries to the Institution's temporary offices, and they will therefore not be accessible for the present, with the exception indicated above.

The Library and Reading Rooms of the Institution of Civil Engineers have been kindly placed at the disposal of members while the Institution is in temporary premises.

The Lending Library has been removed to the Institution's temporary offices and continues to be available for the loan of books to members, who can obtain the same on application to the Secretary.

REPRINTS OF LECTURES.

A limited number of reprints of the following lectures, recently given before the Institution of Civil Engineers (see page 240), are available for distribution, and copies can be obtained on application to the Secretary I.E.E. :—

H. Allcock : "The Decimal System of Weights, Measures, and Coinage."
E. Crammond : "Foreign Trade in its Relation to Investment of Capital."

ROLL OF HONOUR.

(SIXTH LIST.[*])

Killed in Action.

Butler, Lieut. H.	Royal Flying Corps	Graduate
Snowden, Captain S. J.	Middlesex Regt.	Student
Symmes, Major H. C.	South African Infantry	Associate Member

Died of Wounds.

Langdon, Lieut. W. C. C.	Royal Garrison Artillery	Associate Member

Died.

Handcock, Lieut. R. H.	Army Ordance Dept.	Associate Member

MILITARY HONOURS AWARDED.

(SIXTH LIST.†)

C.B.

Le Rossignol, Lieut.-Col. A. E.	Royal Engineers	Member

Distinguished Service Order.

Cunningham, Major T. C.	Royal Artillery	Associate
Dobson, Major J. H.	South African Pioneers	Member

"He repaired a long stretch of railway, and converted motor-lorries to run on rails, by means of which the difficult problem of rationing the force was much relieved. He has performed consistent good work throughout." — *London Gazette*, 13 February, 1917.

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[*] See vol. 54, pp. 64, 447, and 674, and vol. 55, pp. 55 and 193.

† See vol. 54, pp. 306, 518, and 674, and vol. 55, pp. 56 and 193.

[illegible]	[illegible]	[illegible]

[illegible]

Military Cross

[illegible] H. W.	[illegible]	[illegible]
Ditmas, Captain [illegible]	Durham Light Infantry	Associate

"He, accompanied by two other officers, at great personal [illegible] munition dump. His gallant act undoubtedly saved many [illegible]

Hartley, 2nd Lieut. G.	Lancashire Fusiliers	Associate Member

"Although severely wounded, he organized and took out a search party, and for a considerable time under heavy fire [illegible]

[illegible] H. R.	[illegible]	[illegible]

Order of St Stanislas, Second Class (with Swords)

[illegible] A. H. F. S.	[illegible]	[illegible] Member

Order of St Anne Third Class

[illegible] A. H. F. S.	[illegible]	[illegible] Member

Mentioned in Despatches

[illegible]	[illegible]	[illegible]
Fenning, Captain E. G.	Belgian Carrier Corps	Associate
Trevett, Captain C. G.	South African A.S.C.	Associate Member

Mentioned

Aspland, 2nd Lieut. [illegible]	Royal Engineers	Graduate
[illegible] A. H., C.B.	[illegible]	[illegible]
Bland, Captain [illegible]	Royal Engineers	Associate [illegible]
[illegible] Brig.-Gen. [illegible]	Royal Engineers	Member
[illegible] C. M.	[illegible]	[illegible] Member
[illegible] Major W.	Royal Engineers	Associate Member
[illegible] Lieut.-Col. [illegible]	Royal Engineers	Member
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible] Lieut.-Col. H. [illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Frank, Lieutenant R. A.	Liverpool Regt.	Associate Member
Handley, Major A.	Royal Engineers	Member
Hatfield, Captain K. G. S.	General List	Associate Member
Hirtzel, Captain C. H. A.	Royal Flying Corps	Associate Member
Hoskyns, Captain O. P. L.	London Regt.	Associate
Huddart, Major A. H.	Army Service Corps	[illegible] Member
Hutt, Lieutenant A.	General List	Associate Member
Johnson, Lieut.-Col. W. L.	T.F. Reserve	Associate
Layton, Captain A. B.	South Lancashire Regt.	Associate Member
Lefeaux, Captain E.	Royal Engineers	Associate Member
Le Rossignol, Lieut. Col. A. E.	Royal Engineers	Member
McLellan, Captain W.	Northumberland Fusiliers	Member
Mayne, Captain A. J.	Special List	Member
[illegible] Captain J. S.	Special List	Member
Norman, Captain Sir H., Bart.	Special List	Associate
O'Brien, Lieut.-Col. H. E.	Special List	Associate Member
O'Meara, Major W. A. J., C.M.G.	Royal Engineers	Member
Outram, Captain H. W. S.	Royal Engineers	Associate Member
Perrin, Captain E. S.	Royal Flying Corps	Associate Member
Phillips, Major J. H. S.	Royal Engineers	Associate Member
Pickering, Major F.	Cape Fortress Engineers	Member
Simpson, Major A. H. F. S.	Royal Engineers	Associate Member
Vines, Major C. E.	Royal Garrison Artillery	Associate Member
[illegible] Captain R. J.	Royal Field Artillery	Member
[illegible] W. G.	Royal Engineers	Associate Member
Webb-Bowen, [illegible]	Royal Engineers	Associate Member

MEMBERS ON MILITARY SERVICE

(ELEVENTH LIST.*)

[illegible]

[illegible]	[illegible]	[illegible]
Coombs, A. M.	[illegible]	[illegible]
Kelly, A. C.	[illegible]	[illegible]
Mayne, A. J.	[illegible]	[illegible]
Vyvyan, R. N.	Royal Flying Corps	[illegible]
Wilson, J. G.	Royal Flying Corps	2nd Lieut.

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* [illegible]

Associate Members.

Name.	*Corps, etc.*	*Rank.*
Bolton, C. F.	Royal Engineers	2nd Lieut.
Burnet, A.	R.N.V.R.	Lieutenant
Childs, H. B. T.	Royal Flying Corps	Captain
Cooch, H.	R N.V.R.	Lieutenant
d'Andria, A. V.	Royal Engineers	2nd Lieut.
Dewar, M. B. U.	Royal Engineers	Captain
Geipel, K. S.	Royal Engineers	2nd Lieut.
Goodall, F. H.	Royal Engineers	2nd Lieut.
Handcock, R. H.	Army Ordnance Dept.	Lieutenant
Hatfield, K. G. S.	General List	Captain
Humphreys, P. H. I.	Special List	Captain
Jameson, S. T.	Royal Engineers	2nd Lieut.
Lever, G. G.	Royal Flying Corps	
Morris, G. C.	Royal Engineers	2nd Lieut.
Moir, G. H.	Royal Marines	2nd Lieut.
Moore, T.	Royal Flying Corps	2nd Lieut.
Paterson, Q. H.	Royal Navy	Lieutenant
Powell, E. G.	Royal Flying Corps	Captain
Redclift, S. W.	Royal Indian Marine	Elec. Eng.
Redman, R. H.	Royal Engineers	2nd Lieut.
Rouse, F. R. C.	Army Ordnance Dept.	Lieutenant
White, L. W.	Royal Flying Corps	
Wilson, A. L.	Royal Flying Corps	Lieutenant

Associates.

Fenning, E. G.	Belgian Carrier Corps	Captain

Graduates.

Burgess, W.	Royal Engineers	Lance-Corpl.
Geary, F. A.	Royal Engineers	Sapper
Hickie, C. S.	Royal Flying Corps	2nd Lieut.
Hopkins, A. V.	Royal Engineers	Sapper
Sedgwick, A. J.	Royal Engineers	2nd Corpl.
White, A.	Royal Engineers	Sapper

Students.

Anderson, N. L.	Royal Engineers	Sapper
Brown, V. A.	Royal Engineers	Sapper
Chapman, E. D.	Royal Naval Air Service	Air Mechanic
Doran, W. E.	Royal Flying Corps	Cadet
Gee, C. B.	Royal Engineers	Pioneer
Hollin, A. S.	Royal Flying Corps	2nd-class Air Mechanic
Holmes, T.	Royal Engineers	Artificer Cpl.
Hoseason, D. B.	Training Reserve	Private
Iudkevitch, R. M. N.	Royal Engineers	Sapper
Lerpiniere, E.	Royal Engineers	Sapper
Moffat, J.	Australian Flying Corps	Private
Newbury, A. D.	R.N.V.R.	Lieutenant
Parkin, W.	Royal Engineers	Sapper
Peskett, E. G. A.	Royal Flying Corps	Cadet
Sanderson, D. E. K.	Training Reserve	Lance-Corpl.
Stubbings, C. H.	Royal Navy	Eng. Sub Lieut.
Thomas, C. F.	R.N.A.S.	Air Mechanic
Waddington, O. V.	Liverpool Regt.	Private
Wust, A.	Belgian Artillery	Private

PROMOTIONS, TRANSFERS, Etc., OF MEMBERS ON MILITARY SERVICE.

(SEVENTH LIST.*)

Members.

Name.	*Corps, etc.*	*Rank.*
Campbell, A. S.	General List	Captain
Clarke, J.	Royal Engineers	Captain
Coales, J. D.	Royal Flying Corps	Lieutenant
Cormack, J. D., C.M.G.	General List	Colonel
Crawley, C. W. S.	Royal Garrison Artillery	2nd Lieut.
Hall, F. T.	Royal Engineers	Lance-Corpl.
Hamilton, F. T.	Royal Engineers	Captain
Handley, A.	Royal Engineers	Actg. Lieut.-Col.
Harrison, H. T.	R.N.V.R.	Lieut.-Com.
Loos, A. E.	Royal Engineers	2nd Lieut.
McAlpine, G.	R.N.V.R.	Lieut.-Com.
McLellan, W.	Northumberland Fusiliers	Captain
Michod, P. D.	Royal Engineers	Major
Minshall, T. H.	General List	Lieut.-Col.
Monkhouse, S. E.	Royal Engineers	Major
Purves, T. F.	Royal Engineers	Major
Raphael, F. C.	Royal Engineers	Lieutenant
Redman, S. G.	Royal Engineers	Captain
Sparks, H. C., D.S.O., M.C.	Assist. Director of Labour	Lieut.-Col.
Wimperis, H. E.	R.N.V.R.	Lieut.-Com.
Young, H. W.	Royal Flying Corps	Lieutenant

Associate Members.

Anido, A. J.	Royal Engineers	Lieutenant
Anness, E. G.	Royal Engineers	Staff Sergt.
Baker, J. A.	Machine Gun Corps	Lieutenant
Baldwin, L. C.	Royal Engineers	Corporal
Ballard, L. W.	Royal Engineers	2nd Lieut.
Beer, R. G.	Royal Engineers	Actg. Capt.
Blair, F.	Royal Engineers	Captain
Brook, R. V. C.	R.N.V.R.	Lieut.-Com.
Bullock, J. B.	Royal Navy	Eng. Lieut.
Bullough, A. W.	Royal Engineers	2nd Lieut.
Burton, W.	Royal Engineers	2nd Lieut.
Campbell, C. M.	Royal Engineers	Major
Carr, A. S.	Royal Garrison Artillery	2nd Lieut.
Clayton, A. E.	Royal Engineers	Sergeant
Corbett, R. W. T.	Royal Engineers	Lieutenant
Cowan, S. H., D.S.O.	Royal Engineers	Actg. Lieut.-Col.
Crowther, J. P.	Army Ordnance Dept.	Lieutenant
Curtis, H. H.	Royal Engineers	2nd Lieut.
Dalgleish, I. S.	Royal Engineers	Captain
Date, W. H.	Royal Flying Corps	Lieutenant
Davis, A. A.	Royal Engineers	2nd Lieut.
Dixon, W.	Royal Engineers	Lieutenant
Downey, W. E.	Army Ordnance Dept.	Captain
Drury, J. D.	Royal Engineers	2nd Lieut.
Ferrier, S. K.	Royal Garrison Artillery	2nd Lieut.
Frank, R. A.	Machine Gun Corps	Lieutenant
French, Hon. E. F.	Royal Field Artillery	2nd Lieut.
Goolding, C. L.	Royal Engineers	Qmr. Sergt.
Grierson, R.	Royal Engineers	Captain
Harrison, N.	South African Engineers	Actg. Lieut.-Col.
Hirtzel, C. H. A.	Royal Flying Corps	Major

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* See vol. 54, pp. 307, 404, 579, and 675, and vol. 55, p. 59.

ASSOCIATE MEMBERS—*continued*.

Name.	*Corps, etc.*	*Rank.*
[illegible]	[illegible]	Captain
[illegible]	Royal Field Artillery	Actg. Capt.
[illegible]	[illegible]	Lieutenant
[illegible]	Royal Engineers	Actg. Lieut.-Col.
[illegible]	Royal Flying Corps	Lieutenan
[illegible]	Royal Engineers	Actg. Capt.
[illegible]	Royal Engineers	Corporal
[illegible] M., M.C.	Royal Engineers	Actg. Capt.
[illegible] J. W., M.C.	Royal Engineers	Actg. Maj.
[illegible]	[illegible]	Lieut.-Col.
[illegible]	[illegible] Regt.	Major
Mountain, K. A.	Royal Engineers	Captain
Pattman, J. H.	Royal Naval Air Service	Chief Petty Officer
Perrin, E. S.	Royal Flying Corps	Captain
Pyser, M. E.	Royal Engineers	2nd Lieut.
[illegible]	[illegible] Engineers	Corporal
Ripley, H. S.	Royal Engineers	Captain
Ross, J. D.	Royal Engineers	Lieutenant
[illegible]	Royal Engineers	Sergeant
Salt, C. W.	Royal Engineers	Lieutenant
Sargent, G. H.	Machine Gun Corps	Lieutenant
Schultz, A. H.	South Lancashire Regt.	Major
Simpson, A. H. F. S.	Royal Engineers	Major
Singleton, C.	Royal Engineers	Lieutenant
[illegible]	New Zealand Engineers	Captain
Strange, J. P.	Royal Engineers	Cadet
Stuart, C. E.	Royal Flying Corps	Sergeant
[illegible]	South African A.S.C.	[illegible]
Trippe, C. F.	Royal Engineers	Actg. Capt.
Wallis, T. S.	Royal Engineers	Lieutenant
White, E. S.	Royal Engineers	2nd Lieut.
Wright, F. T.	Army Ordnance Dept.	Captain
Young, C. R. M	Royal Garrison Artillery	Actg. Maj.

ASSOCIATES.

[illegible]	Hong Kong Engineers	2nd Lieut.
Dittmas, F. I. L. M.C	Durham Light Infantry	Captain
[illegible] W.	Royal Flying Corps	Captain

GRADUATES.

Broadwood, L. A. T.	Royal Engineers	Actg. Capt.
[illegible]	Army Ordnance Dept.	Captain
[illegible] H.	R.N.V.R.	Sub-Lieut.
[illegible]	Army Service Corps	Captain

GRADUATES—*continued*.

Name.	*Corps, etc.*	*Rank.*
[illegible]	Royal Engineers	Qmr.-Sergt.
Lacey, F. P. S.	Army Service Corps	2nd Lieut.
Monks, C. E.	Royal Lancaster Regt.	Lieutenant
Preston, E. B.	Royal Engineers	2nd Lieut.
Walker, R. B.	Yeomanry	Major
Wynyard-Wright, V. T.	Indian Army Reserve of Officers	Lieutenant

STUDENTS.

[illegible]	Royal Engineers	Mechanist Staff Sergt.
Bellamy, H. E.	Royal Flying Corps	Lieutenant
Burton, R. G.	Royal Engineers	Lieutenant
Chadwick, E. L.	Royal Flying Corps	Lieutenant
Duckworth, E. H.	Royal Engineers	Lieutenant
Edminson, E.	Machine Gun Corps	2nd Lieut.
Ferranti, B. Z. de, M.C.	Royal Garrison Artillery	Actg. Maj.
[illegible]	Royal Engineers	Corporal
Gibson, H. C.	Royal Engineers	2nd Lieut.
Hayes, L. W.	Royal Engineers	Cadet
Hedgcock, A. D.	Royal Engineers	Lieutenant
Hogarth, J. E.	Army Service Corps	Private
Jenkins, A. M.	Royal Engineers	Lieutenant
Macklin, R. W.	Royal Garrison Artillery	Actg. Capt.
Marx, R., M.C.	Royal Field Artillery	Actg. Maj.
Moody, H. T.	Royal Engineers	[illegible]
Mowat, J. W.	Highland Light Infantry	Corporal
Peter, L. H.	Royal Flying Corps	Captain
Protheroe, R. N. L.	Royal Field Artillery	Actg. Capt.
Riley, T. S.	Army Service Corps	2nd Lieut.
Shaw, C. G.	Royal Engineers	Lieutenant
[illegible]	Royal Engineers	Lieutenant
Sherwell, O. W., M.C.	Royal Field Artillery	Actg. Capt.
Smith, R. H.	Royal Engineers	Lieutenant
Tilson, H. S.	Royal Engineers	2nd Lieut.
Trouton, D. G.	Royal Field Artillery	Actg. Capt.
Voss, H. A.	Royal Engineers	Lieutenant
Wadeson, M.	Machine Gun Corps	Lieutenant
Wenger, T. L.	Machine Gun Corps	Lieutenant
Wheeler, P. J.	Royal Field Artillery	Lieutenant
Wooler, L. S.	Royal Artillery	Lieutenant

INSTITUTION STAFF.

Ashford, H. J.	Royal Fusiliers	Private
Crowther, W. V.	Royal Garrison Artillery	2nd Lieut.
Grant, F.	Royal Flying Corps	1st-class Air Mechanic
Skinner, C. W.	Honourable Artillery Company	Lance-Corpl.

THE JOURNAL OF
The Institution of Electrical Engineers

Vol. 55. MAY, 1917. No. 266.

WAYLEAVES.

By C. VERNIER, Member.

(*Paper first received* 15 *February, and in final form* 19 *March*, 1917; *read before* THE INSTITUTION 12 *April, before the* NEWCASTLE LOCAL SECTION 16 *April, and before the* YORKSHIRE LOCAL SECTION 25 *April*, 1917.)

The question of securing facilities by legislation for carrying electric mains over and upon private land has frequently been referred to in discussions before the Institution and elsewhere.[*]

So long ago as 1905 when Mr. G. L. Addenbrooke read a paper entitled "The Value of Overhead Mains for Electric Distribution in the United Kingdom,"[†] references were made to the difficulties which were then being experienced, and which it was anticipated must inevitably be experienced in a greater degree as the use of overhead mains tended to become more general. In this paper some particulars were also given of the admirable legislative provisions afforded for the erection of overhead and underground mains on private property in Italy[‡] and Switzerland.[§]

During the 12 years which have since elapsed, the need for such facilities has become more and more insistent. Electric power supply, as we know it to-day, was then in its infancy, and although between 1,000 and 2,000 route miles of overhead electric mains[||] have already been erected under the difficult conditions at present obtaining in this country, the time has come to consider seriously whether the important services which public suppliers of electrical power, light, and heat, must continue to afford—and certainly in a greater measure than ever before—to our industries, manufacturers, railways, and the practically untouched field of agriculture, in the strenuous and difficult times which will follow the present European conflict, do not call for prompt legislative assistance in removing certain difficulties which at present hamper their fullest development.

The need for efficiency and economy will be so seriously accentuated, both in regard to a more efficient utilization of our seriously depleted capital and also in regard to the conservation of our natural resources, of which in this country coal is unquestionably the most important, that there is every reason to expect that electrical services which can so eminently achieve both these objects will be sought for to an unprecedented extent after the War.

I do not propose to recapitulate the advantages and economies which can be derived from the generation of electrical energy on a large scale, or from the centralization or linking up of existing electricity supply undertakings. These questions have been already so fully discussed in papers and addresses published within recent years[*] that I may fairly assume that they are now generally recognized. I am all the more readily disposed to adopt this view in that it has received striking confirmation by the formation recently of various committees to give effect to the policy of linking up existing undertakings as suggested by the Board of Trade, as well as to consider the much more ambitious project of a fully national scheme of electric power supply. At the outset let me say that the present paper is more closely concerned with securing to the fullest possible extent the advantage of the economies in capital cost which can be effected by the use of overhead wires for interconnecting, transmitting, and distributing mains across open country, and the no less important economies which can be obtained by laying underground mains wholly or partly on private property whenever the use of such mains is found desirable. My remarks, however, must not necessarily be taken as applying to overhead wires in towns and villages, which stand in a somewhat different category. The economies above referred

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[*] G. L. ADDENBROOKE, *Journal I.E.E.*, 1905, vol. 34, p. 511; W. B. WOODHOUSE, *Ibid.*, 1910, vol. 44, p. 802; C. VERNIER, *Ibid.*, 1914, vol. 52, p. 17; B. WELBOURN, *Ibid.*, 1914, vol. 52, pp. 117, 217; J. R. BEARD, *Ibid.*, 1916, vol. 54, p. 127; R. A. CHATTOCK, *Proceedings of the Annual Convention of the Incorporated Municipal Electrical Association*, 1914, p. 3; W. T. KERR, *Ibid.*, 1916, p. 158; "Wayleaves," *Electrical Review*, 1916, vol. 79, p. 527.

[†] *Journal I.E.E.*, 1905, vol. 34, p. 511.

[‡] Appendix 1.

[§] Appendix 2.

[||] Not necessarily all on private property.

[*] S. Z. DE FERRANTI, *Journal I.E.E.*, 1910, vol. 46, p. 6; C. VERNIER, *Ibid.*, 1914, vol. 52, p. 17; J. A. ROBERTSON, *Ibid.*, 1914, vol. 52, p. 32; J. R. BEARD, *Ibid.*, 1916, vol. 54, p. 127; E. T. WILLIAMS, *Ibid.*, 1916, vol. 54, p. 581; R. A. CHATTOCK, *Proceedings of the Annual Convention of the Incorporated Municipal Electrical Association*, 1914, p. 3; C. H. MERZ, British Association, 1916, *Electrician*, 1916 vol. 77, p. 915; R. P. SLOAN, *Ibid.*, p. 917.

[illegible] emphasized in previous [illegible] they only need be briefly mentioned here. It will be sufficient to state that on 20,000-volt mains the saving in capital cost which can be effected over an equal length of route by the use of overhead wires as against the use of underground cables is in the neighbourhood of 50 per cent, excluding the cost of wayleaves in each case. At higher voltages it is yet greater ; while by [illegible] mains, instead of keeping strictly to public roads, a saving in capital cost of 30 per cent is not uncommon on routes of several miles, [illegible] the result of shortened [illegible] the ground. It must further be borne in mind that although the Board of Trade are willing to allow extra-high-pressure overhead lines on public roads, subject to strict requirements regarding public safety, practical considerations usually render this, if not quite impracticable, at least extremely undesirable, and therefore all such lines must ordinarily be placed on private property.

We have also to face the probability that, in the near future, much higher transmission pressures will be employed, and this cannot in the present state of the art be satisfactorily dealt with (if at all) by underground cables. The difficulties already referred to in the use of overhead wires for extra-high-pressure transmission, fall conveniently under two heads, viz. "Consents" and "Wayleaves."

Part 1.

[illegible]

The [illegible] Lighting Acts contain the following clauses :—

[illegible] 1882.

[illegible] anything in this Act or in any Act [illegible] shall not be authorized to place any electric line above ground, along, over or across any street without the express consent of the local authority, and the local authority may require the undertakers to forthwith remove any electric line placed by them contrary to the provisions of this section, or may themselves remove the same, and recover the expenses of such removal from the undertakers in a summary manner ; and where any electric line has been placed above ground by the undertakers [illegible] jurisdiction upon complaint made, if they are of opinion that such electric [illegible] to the public safety, may, notwithstanding any such consent as aforesaid, make an order directing and authorizing the removal of such electric line by such person and upon [illegible]

[illegible]

The undertakers shall not, without the express consent of the Board of Trade, and where the local authority are not themselves the undertakers, of the local authority also, place any electric line above ground except within premises in the sole occupation or control of the undertakers, and except so much of any service line as is necessarily so placed for the purpose of supply.

In considering these clauses it is necessary to differentiate between the various classes of undertakings, viz. statutory municipal and statutory company undertakers, and non-statutory undertakers. The above clauses, it will be seen, compel statutory undertakers to obtain the consent of the local authority to the erection of overhead mains everywhere outside their own premises. This consent is obviously unnecessary in the case where a local authority are themselves the undertakers, supplying only within their own district, and such consent in the case of a local authority would only be required in the exceptional case of a municipal undertaking wishing to erect overhead wires for giving a supply outside the area scheduled in the Order and in the district of a neighbouring local authority under powers conferred by section 6 of the Electric Lighting Act 1909.

For a statutory company undertaking, the consent of the local authority is in every case essential ; and further, there can be no appeal from the decision of a local authority in this matter, which may refuse its consent without assigning any reason or may attach unreasonable and onerous conditions thereto, or cause unreasonable and vexatious delays. There is only one usual exception to this procedure, i.e. in the case of the Power Acts where an appeal to the Board of Trade is allowed in the event of a consent by a rural district council being unreasonably withheld.

The anomaly of the position will be better appreciated when it is pointed out that any private individual or company who cares to undertake the transmission or distribution of electricity without statutory powers—which can be and is commonly done, for example, by colliery and quarry owners and others, as there is no restriction placed upon it so long as electricity supply to consumers is not the chief business of the undertaker*—is perfectly free to erect overhead wires over private land without the consent of the local authority, and can quite well carry such wires across public roads and footpaths, provided the local authority are not the owners of the land on either side of the road and that care is taken not to contravene any by-laws which the local authority may have adopted,† and further, in the absence of special by-laws that the highway is not itself interfered with or broken up, and that its ordinary use is not restricted in any way.

The following examples may be cited to show the difficulties and delays resulting from the application of the present Acts in the case of statutory company undertakings.

(1) Application was made to a local authority for their consent to the erection of a portion of a long overhead line which passed through their district, and which was to be placed entirely on private land, except where it crossed over a public road and a privately owned footpath but with a public right of way over it. No reply or acknowledgment was given for nearly two months, when a letter [illegible]

[illegible]

* [illegible]

† [illegible]

and asking to be referred to the applicants' statutory powers. After this had been done, objection was raised to the route, which he maintained was too near to the footpath in question, and also too near to some farm buildings in another part of the route. In making these objections, he stated that he was aware of course of the functions of the Board of Trade, but that evidently from the provisions of the Act of Parliament, some duty having reference to the safety of the public is imposed upon the local authority. All representations to the effect that questions of public safety might very well be left with the Board of Trade, which is specially charged with these matters, were of no avail, and negotiations had to be re-opened with three separate parties in order to alter the route. After 7 months had elapsed from the date of the original application, and notwithstanding repeated applications to be allowed to proceed with the work—which owing to the delay was causing great inconvenience and loss to an important industry—a reply was received pointing out that the only alternative to the erection of the line at the sole risk of the undertakers, was the procuring of the consent of the local authority, and that such consent would not be given without an agreement. A further delay occurred while an agreement was drawn up, before it was felt reasonably safe to undertake the erection of any part of the line in this district. In this case 7½ months elapsed before a commencement could be made with the work, and 9 months before the consent was finally given.

(2) An application was made to another local authority for a consent in similar circumstances to the previous case. No undue delay occurred in this case in giving a reply, which was to the effect that consent would be given, provided the following conditions were agreed to :—

(*a*) That where the line crossed any road, street, or footpath, it must be placed underground at a minimum cover of 3 ft.

(*b*) That if any new road or street is laid out on the land where the line is situated, the line shall within 14 days (subsequently extended to 3 months) be placed underground.

It was represented to this authority that the Board of Trade allowed the carrying of electric wires overhead across roads with their approval as being perfectly safe, and a list of similar overhead crossings already erected with the consent of the local authority and of the Board of Trade in the neighbouring districts were submitted, and an invitation extended to inspect them. This was not accepted, and finally an interview was sought with the committee dealing with the matter.

At this interview questions were asked as to the particular objections to putting the line underground at each footpath and road. The technical objections to the insertion of lengths of underground cables into extra-high-tension overhead lines were explained as well as was possible to the non-technical mind, and the further objection of the increased and unnecessary expenditure which would be incurred in complying with this condition was pointed out.

No sooner was additional expense mentioned than further discussion was stopped and an intimation given that the reply of the local authority would be communicated in due course. This, as might be expected from the interview, merely re-affirmed the previous conditions, which finally had to be accepted.

(3) In another case application was made to a rural district council for their consent to the erection of overhead wires wholly over private land, except where roads and footpaths were met with. This consent was granted on condition that the line be placed underground where it crossed any road, bridle-path or footpath, not only in connection with that application, but also in any future ones. An interview was obtained with the council, at which the matter was discussed, but they declined to modify their former resolution. Fortunately, in this case, the local authority being a rural district council, there was a right of appeal to the Board of Trade. Such an appeal was therefore entered and subsequently allowed by the Board of Trade. The total time taken to obtain this consent was over 9 months.

These examples may serve to illustrate how many of these local authorities have but the haziest idea of why they stand possessed of the powers conferred in the clauses of the Acts already quoted. Some, and fortunately a good proportion of these local authorities, treat the matter as a mere formality to be complied with by the undertaker and consent readily; others, as we have seen, in the absence of proper enlightenment, usurp functions which properly belong to the Board of Trade; while in other cases it is difficult to discern the existence of that public spirit which one might look for in the representatives of an important community.

I am strongly of the opinion that it is essential that a right of appeal to the Board of Trade should be allowed in all cases, and that while the local authority should have the right to be heard, it should have no absolute veto on such questions, and that all powers of interference in technical questions, such as design and questions of the public safety, without a reference to the Board of Trade, should be absolutely taken from them.[*]

A time limit should further be determined, say one month, as in the case of works on public roads, during which a local authority must either signify or refuse its consent, failing which such consent will be deemed to have been given, as the unreasonable delays which are at present possible in some cases should not be tolerated.

If there be any insuperable objection to extending the right of appeal in the somewhat special case of county boroughs, it should nevertheless be applied to urban district councils as well as to rural district councils.[†]

Many urban areas, at least in industrial districts, partake of the character of rural districts in their sparsity of population, and quite a large part of an industrial county, and often just that part where overhead wires are most needed, may comprise a number of contiguous urban areas.

Part 2.

WAYLEAVES.

Electricity supply, also gas and in some cases water, undertakers are precluded by law[‡] from laying their mains in private lands without special consent, and this is

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[*] A local authority under Section 6 of the Electric Lighting Act 1882 may make by-laws for the safety of the public, but these by-laws must always be confirmed by the Board of Trade.

[†] This has already been allowed in a few cases in power companies' Acts, e.g. Kent Electric Power Act 1906, Section 22.

[‡] Waterworks Clauses Acts 1847, Section 29; Gasworks Clauses Acts 1847, Section 7; Appendix to Electric Lighting (Clauses) Act 1899.

[illegible] the undertakers.

[illegible] are already available—and includes generally all private property, agricultural and other open land, such as parks, [illegible] land, etc., and private lands owned by [illegible].

The above restrictions have been found to be a source [illegible] ge scale, and in the full achievement of the economies resulting therefrom.

Cases of absolute refusal to grant an easement or wayleave have been in my experience fortunately of rare occurrence, but it is otherwise with the imposition by landowners of unnecessarily oppressive conditions, chiefly the [illegible] owner, and with some exceptions in their exercise of procrastination and utter indifference to industrial needs in dealing with such matters.

Only a very few cases need be cited, as doubtless the ensuing discussion will bring to light many others :—

(1) A landowner (an eccentric old lady), without assigning any reason, refused to allow any cables, pipes, or poles whatever on her land.

(2) The agent to a large landowner, when first ap[illegible] inclined to grant a wayleave on reasonable [illegible]quently, owing to a claim for damage having been served upon a firm in which this agent was interested (unknown at the time to the applicant) he plainly intimated that he would set one case against the other. He was subsequently induced to moderate his views, but the claim for damage had eventually to be abandoned.

(3) A landowner, after leading the applicant to believe that a certain wayleave over his land would be granted, kept delaying his final consent on some pretext or other. After 9 months of this sort of thing, when pressed more than usual, he took offence and definitely refused to consider the matter any further. It was therefore necessary to incur additional expense in laying this section [illegible] fortunately provided an alternative.

[illegible] were only held [illegible]ve. After repeated [illegible]mittee had been appointed, [illegible]

It was thereupon decided to divert the route in order to overcome this further delay. This being found too costly, [illegible]ened in the following month, and a [illegible] would be granted, [illegible] the district. After a long delay, while terms for this supply, which necessitated a special main, were being arranged, and 12 months from the date of the original application, it was stated that certain lessees of the land challenged the right of the trustees to grant this wayleave. Negotiations then took place between the parties, which took up another 6 months, and it was fully 18 months before the permission could be obtained to start work.

The line was nearly 20 miles long and all other wayleaves had been granted some 9 months before this last consent could be obtained.

(5) A colliery company owning land in various parts of the district held up wayleaves in two places on overhead lines some 30 miles long, taking advantage of the opportunity offered to negotiate favourable terms for a supply of electricity to a colliery.

This sort of case is likely to become more troublesome in future, as colliery owners have in recent years adopted the policy of purchasing agricultural land, in order to avoid heavy claims for compensation for damage arising from subsidence from their workings.

It is only fair to mention that, as a rule, where a landowner employs a full-time agent to look after his property, delays are seldom so serious as in the case of smaller owners who have to deal with the matter themselves or through a solicitor. As it is not at all unlikely that we shall witness a break-up of large estates into smaller holdings after the War, unless some measure of compulsion is granted before this happens, our difficulties will be much accentuated and may become wellnigh intolerable.

A frequent cause of prolonged delay is that one or more owners, after the usual initial delay in replying, which varies according to the individual, make objection to the route selected over their land. Negotiations must then be reopened with other owners, who probably have already given their consent, to allow of a diversion of the route on their estate, and in consequence they not infrequently come to the conclusion that the applicant does not know his own mind, which is not usually conducive to a speedy settlement. If in addition a local authority should call for a diversion of the route when negotiations with landowners are well advanced, it is readily perceived how delays become cumulative.

I purposely refrain from quoting some of the onerous conditions which landowners have sought to impose, in some cases with success, as in the existing condition of things such information might adversely affect future negotiations.

Cost of wayleaves.—Compensation for an easement or wayleave is almost invariably given in the form of an agreed annual rent, based either on a fixed sum per pole or per yard of route, or an annual lump sum payment to cover a particular stretch of route between fixed points.

Rents have steadily risen during the past 7 years and especially since the War began.* This is partly because landowners who at first treated wayleave rents merely as a convenient addition to the rents which they already received for the ordinary use of their land, have more and more come to regard wayleave rents as quite a useful [illegible]

[illegible]

* [illegible]

War scale of taxation came into force, have made the most of their opportunities.

Moreover, as it is usually quite impossible to bring the slightest pressure to bear in negotiations for wayleaves, it has in unavoidable cases been necessary to pay some recalcitrant landowner a heavier rent than usual in order to complete wayleaves for a route, the alternative possibly being a diversion of the route on adjoining estates and many more months of delay, or possibly heavy expenditure in circuiting his estate, usually both.

Other landowners have come to hear of this rent, and have asked for the same terms. In a recent case in my experience, the agent to a landowner had quoted a certain figure—a figure already agreed to by him in previous cases—for a wayleave for an underground cable along a road and across fields on his estate. He subsequently had a conversation with another land agent, who had held out for a heavy rent, which after a good deal of hesitation, and for reasons such as I have just mentioned, it had been decided to agree to. The former agent then frankly stated that he would have been quite willing to grant the wayleave on his usual terms, but as we had agreed to give another this rent, he could not accept less. This was exactly double the rent he had previously asked.

For obvious reasons, I must only speak of the cost of wayleaves in general terms, but the following examples may serve to indicate the measure of the extortionate demands which are exacted :—

(1) At the present time, ignoring for the moment the formidable difficulties in renting land just when and where it is required, it would be more advantageous, on financial grounds alone, to electrical undertakers in some parts of the country to rent a strip of land wide enough for many a London street for the whole length of an overhead line at the same rents per acre as landowners secure from their tenants for some of the very best of the agricultural land in this country, and such that even if this strip of land were put to no other use the landowner would suffer no pecuniary loss.

(2) Alternatively, and subject to the same assumption, it would in many cases be a satisfactory business proposition from the point of view of the undertakers to rent the whole area of specified fields along the route, on agricultural tenant's terms, provided the right to sub-let again for agricultural purposes were allowed.

The iniquity of these charges can be further appreciated when it is mentioned that only approximately one-half of 1 per cent, on a liberal estimate, of the land mentioned in paragraph (1) is actually diverted from its ordinary use in connection with an overhead line on arable land, and less than one-quarter of 1 per cent on grazing land.

If these charges may fairly be termed iniquitous in the case of overhead lines, what should be said of the same rents which are now frequently asked for wayleaves for underground cables? Underground cables when once laid generally require no further attention for many years, and do not obstruct or interfere in any way whatever with the ordinary use of the land ; in fact, their very existence is usually forgotten by everyone except the undertaker and the grantor of the wayleave when he receives his rent.

In order to prevent any misunderstanding, let me add that rent is not the only compensation, and that additional compensation has to be paid to the landowner, tenant, or occupier for all damage to crops, grass, roads, lands, drains, fences, trees, etc., occasioned in the laying down or erection of the work, or its subsequent repair and maintenance, while invariably there is a clause in the agreement for the diversion of the main at short notice at the sole cost of the undertaker.

No reasonable person would quarrel, in principle, with the payment of this further compensation, and although something might also be said on this subject, considerations of space do not permit of this in the present paper.

Hitherto I have only discussed the landowner's rent, but the tenant or occupier (if any) has also an interest in the land, for which he should receive compensation. There are alternative methods of dealing with the occupier. The first is to agree upon terms with the landowner on the understanding that he settles with his own tenant. This is the basis on which the cost of wayleaves discussed above has been considered. As a rule, landowners prefer this procedure, as they do not like third parties discussing terms with their tenants, but no doubt also for the very good reason that tenants not infrequently complain of not receiving any compensation at all from their landlords, who sometimes do not even take the trouble to advise their tenants of the proposed work.

The second method sometimes adopted is to agree upon a rent with the landowner based on the applicant agreeing to make terms with the tenant. This method has the advantage that the tenant, who after all suffers such inconvenience and interference as there may be, secures compensation, but as it at least doubles the number of negotiations, and as occupiers are frequently more difficult to deal with than the landowners themselves, having a more direct and personal interest in the use of the land, it is not a method to be recommended.

Compulsory powers for expropriation.—Before discussing possible remedies for this state of things, it will be well to draw attention to two points of view from which the question of electricity supply undertakers being granted compulsory powers for carrying their mains over or through private land may be regarded. These are briefly, on the one hand, that such undertakings afford a valuable public service, and that any source of unnecessary expense in furnishing such service is ultimately a serious handicap to industry and production, and consequently contrary to the national interest. The other is that these undertakings—I here refer to company undertakings—are a source of private profit, and any saving of expenditure merely increases profits to shareholders.

The latter is undoubtedly the view that weighs chiefly in the minds of the majority of individuals and private and public bodies when they have the power, as in this case, to exercise their absolute discretion in granting or refusing a concession. Although it is evident that Parliament has already afforded some measure of recognition to the public service character of electricity supply undertakings, especially power company undertakings, by the grant of special privileges, such as the right to break up streets and roads, the compulsory acquisition of land for their works, and, on the other hand, the imposition of specified duties under penalties, and of control, including the regulation of maxi-

[illegible] and dividends, it does not appear hitherto to have fully recognised the vast and important part which electricity supply has played in the national economy during the past [illegible] years, or possibly it is destined to play in [illegible] larger and even perhaps in extraordinary degree in the near future, provided encouraging facilities are afforded for its development.

Compulsory powers for expropriation for works of public utility, or as is better known in the United States, the power of eminent domain, i.e. the sovereign right of a State to appropriate private property to public uses, whether the owner consents or not, exists in most European States, including Italy, Switzerland,[*] France,[†] Norway,[‡] Spain, Holland, Belgium, and possibly other countries, and also in the United States.

In Italy,[§] Switzerland, and France[¶] further enactments on expropriation have been applied to the carrying of electric mains (either overhead or underground) over or through private land, while in Norway the general law on expropriation is available for this purpose. I have no information as to whether this is also the case in Spain, Holland, or in pre-War times in Belgium, but as these countries have existing laws on expropriation for works of public utility, it is very unlikely that their application to the special case of electric mains will have been overlooked.

In every case it is necessary to satisfy the authorities, i.e. either the Crown, the Legislature, or a Government Department, that (*a*) the undertaking or (*b*) the proposed main is one of public utility, before these powers can be applied.

In the United States under a recent law, easements for rights of way over public and national lands can be granted by the State,[*] but I am not aware that otherwise the ordinary procedure is in any way different from ours, i.e. by negotiation and agreement with the owners. Owing to the comparatively low cost of land in many parts, however, it is quite a common practice for electric light and power undertakings to purchase a strip of land for at least their most important lines, and elsewhere to use the public roads [illegible] compulsory powers may exist in some of the States and not in others, for, as is well known, each State in a large degree makes its own laws.[‖]

The United Kingdom and Germany are the only two large European States which, having reached a high state of industrial development (perhaps in some measure because of this), have not yet adopted compulsory powers for expropriation for electric mains on private property.

We may quite well leave Germany to work out her own economic salvation after this War, only we must not overlook the fact that she is not unconscious of the need for such powers as an important factor in her post-War industrial and economic rehabilitation.[*]

In this country, with a few exceptions, which I shall shortly describe, and excepting the extraordinary War-time procedure under the Defence of the Realm Acts, the only statutory powers which are at all analogous to the right of expropriation or of eminent domain, are the compulsory powers for the purchase of land under the procedure laid down in the Lands Clauses Acts. This procedure is, however, in ordinary cases only available if secured by a special Act of Parliament or by a Provisional Order of a Government Department confirmed by Parliament, and, owing to the great cost and delay of conducting a Bill through Committee, can usually only be exercised in connection with public works of great magnitude, such as railways, docks, harbours, and the like. The price of land acquired in this manner is always excessive, and in some cases many times its real value.[†]

We are not here, however, concerned with the purchase of land for routes for our mains, nor should this be at all necessary. The present procedure for the compulsory purchase of land, as will be observed, is altogether too clumsy and costly to render its adoption practicable for such a purpose.

There are, however, interesting precedents in our own legislation which affords to certain authorities the right to secure compulsory easements over private land.

(*a*) A local authority under the Public Health Act 1875 may carry sewers through any private land whatsoever within or without their district, and where a local authority supplies water within their district, they have the same powers for carrying water mains within or without their district, in either case without taking the land or purchasing an easement, but only subject to compensation. The material clauses dealing with these powers are Sections 16, 26, 32, 33, 34, 54, 305, and 306 of the Public Health Act 1875.[‡]

Clause 26, it may be remarked, is an unusually drastic one, as it goes so far as to prevent a landowner from erecting a building on his own land over a sewer or a pipe of the local authority (if an urban district) without its consent, under pain of severe penalties and the right of the local authority to pull it down at the cost of the offender.

(*b*) Under a recent Act passed last year—Telegraph (Construction) Act 1916 §—the Postmaster-General is empowered to erect or lay down overhead or underground telegraphic lines on private land by serving a notice upon the owners, lessees, or occupiers of the same, and any difference between the parties is to be referred to a stipendiary magistrate or judge of a county court or in Scotland a sheriff, with a right of appeal to the Railway Commissioners.

[illegible]

[illegible]

[*] [illegible]

[illegible]

[*] [illegible]

[†] [illegible]

[‡] See [illegible]

[§] See [illegible]

It is not without interest to observe the gradual relaxation of restrictions in course of time, as under previous Telegraph Acts[*] such powers as were allowed were designed to meet exceptionally difficult cases: for instance under Section 2 of the Telegraph Act 1892 the motive is that the inhabitants of any district or a public authority *are debarred from the public convenience of telegraphic communication* owing to the refusal by the landowner and others to consent to the construction of a work by the Postmaster-General, while under a later Act (Section 4 of the Telegraph Act 1908) the consideration is that, owing to such refusal, telegraphic communication cannot be supplied to any district or place *except at unreasonable cost or on unreasonable conditions.* In each of these cases if the owner, lessee, or occupier objects, the question must be referred to Parliament.

Finally, in the Act of 1916 there is no restriction as to motive, so long as the proposed line *is in the public interest* and there is no longer any special reference to Parliament.

So far as I am aware, there is not a single case in which the powers conferred by the Telegraph Acts of 1892 and 1908 have been exercised, and the working of the more recent Act of last year will be watched with great interest.

(*c*) In India under powers conferred by the Indian Telegraph Act 1885, the telegraph authority is entitled to place telegraph lines and posts in or upon any immovable property.[†]

Our special interest in these clauses lies in the fact that they have been extended to electricity supply undertakers in certain cases, and also in regard to the diversion clause contained in Section 17.[‡]

The Land Enquiry Committee's Report.—In 1912 the then Chancellor of the Exchequer (Mr. Lloyd George) appointed a small private committee to enquire amongst other matters into the "nature and workings of the existing systems of ownership, tenancy and taxation and rating of land and buildings in urban districts and the surrounding neighbourhoods, and their effect on industry and the conditions of life." The report of this committee was subsequently published in two volumes,[§] one of which refers [||] to the question of wayleaves in the following terms :—

"Public bodies are often called upon to pay large sums for such easements, and private firms are affected similarly when they are unable to get consent to the laying of pipes for the service of necessary water or electrical power. By Section 29 of the Waterworks Clauses Act 1847, and Section 7 of the Gasworks Clauses Act 1847, water and gas companies are expressly precluded from laying pipes or any other works on private lands without the consent of the owners, though by the same Statutes they are allowed to lay pipes, and examine and replace them from time to time under public streets. These provisions enable owners to demand large sums from such companies for wayleaves. Modern developments of the use of electricity to supply power at a distance from the spot where it is generated have given increased importance to this question. Wires have to be carried across country, and here too each owner whose land it is proposed to traverse is enabled to hold the scheme up by demanding an excessive price for permission to carry the wire across his land. In some cases he is enabled to prevent it altogether. . . . We believe that the State should exercise the power of compelling the grant of easements and wayleaves of all kinds.

"RECOMMENDATIONS."

"Therefore we recommend :—

"(1) That the Government Department authorized to give such sanction should have the power to make an order for the compulsory acquisition of easements or wayleaves for any purpose.

"(2) That in all cases where any such order is made the terms should be fixed by the Judicial Land Commissioners.

"(3) That in all cases :

"(*a*) The local authority and the landowner should both be enabled to appear before the Government Department and the landowner before the Commissioners.

"(*b*) The amenities of the neighbourhood and the interests of the landowner should be considered, and injured as little as possible.

"(*c*) The term 'landowner' should include all who have substantial interests in the property."

On the question of the present procedure for assessing compensation under the Lands Clauses Acts,[*] the Committee state [†]:—

"We are of opinion that a permanent tribunal cheap and easy of access, with wide powers in respect of limiting evidence and disallowing costs, should be submitted for the present procedure. Such a tribunal would take the form of a court or a commission combining a strong judicial element with expert members. The latter should be professional men not in private practice who would be retained in the service of the court or commissioners, thus adding independence of judgment to their professional skill. We had intended to recommend a court, but the proposals of the Government to constitute a body of Judicial Land Commissioners for dealing with questions of tenure and compensation fully meet our views.

"Therefore we make the following recommendations with regard to the tribunal for assessing compensation, its procedure and costs [‡] :—

"TRIBUNAL AND PROCEDURE."

"(*a*) That in all cases where land is acquired under compulsory powers, the final determination of the purchase price, the assessment of the compensation for severance and disturbance due to the claimant, and the apportionment of the compensation as between several claimants, should be determined by the Judicial Land Commissioners.

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[*] See Appendix 5.

[†] See Appendix 6.

[‡] J. W. MEARES : *Journal I.E.E.*, 1916, vol. 54, p. 504.

[§] "The Land—The Report of the Land Enquiry Committee," vol. 1 (Rural), vol. 2 (Urban) (Hodder & Stoughton).

[||] Vol. 2, p. 339.

[*] See Appendix 7.

[†] "The Land," vol. 2, p. 303.

[‡] This is the tribunal recommended by the committee to fix compensation for wayleaves.

"(c) That the procedure for determining the amount of [illegible] should be as follows :—

"(1) At the time of applying for compulsory powers the promoters should serve a notice on the district valuer and all interested persons, as to the lands to be acquired.

"(2) [illegible] compulsory powers are obtained the district valuer should assess the market value of the property to be acquired, as at the time of the application for compulsory powers provided that where the owners or persons interested are unable to agree to the valuation they should have the right to appeal to the Land Commissioners against the valuation of the district valuer.

[illegible]

"[illegible] recommend that

"(a) [illegible] should be prepared by the commissioners.

"(b) It should be in the discretion of the commissioners to award the whole costs of arbitration in any proportion as between the promoters and the claimants provided that—when the finding of the commissioners is less than the offer made by the promoters, the costs should be paid by the claimant, unless otherwise ordered by the commissioners.

"(c) The commissioners should have discretion to limit the number of witnesses and to exclude counsel."

I have freely quoted from the above report, as, in my opinion, not only would the adoption of the Committee's recommendations go far to overcome satisfactorily most of the present difficulties in connection with obtaining wayleaves, but, further, any action which might be taken in order to secure legislative assistance would, if on these lines, be more likely to meet with Government support.

It will probably be known that the report formed the [illegible] the Government by Mr. Lloyd George at Bedford and Swindon in October 1913, which included the formation of a Ministry of Lands and the appointment of Judicial Land Commissioners.

[illegible] I believe that the War will have facilitated [illegible]

[illegible] e. legislators and the public alike, to [illegible]

It is obvious that no new legislation of this nature can be considered by Parliament during the period of the War and for some time after, but I suggest that the Council of the Institution would do well to formulate proposals and consider without delay the best means of securing their adoption.

The Land Committee's recommendations have, however, one serious defect, in that no definite period of time is appointed during which consents must either be given or an Order be made by the Government Department concerned. Time is all important in industrial matters, and it is, for instance, very little use to tell a colliery proprietor that he may be given a supply perhaps 6 months, perhaps 12 months, later—and with no guarantee of any sort that it might be more or less—provided the wayleaves can be successfully negotiated or that a Government Department thinks fit to make an Order.

It appears inconceivable that the present procedure in connection with the acquisition of land for general public purposes, including electricity supply, can for long remain unchanged after the War, but in the event of the Govern- [illegible] able period after the declaration of peace with the former proposals for a Ministry of Lands, and the constitution of Judicial Land Commissioners or other new proposals, I submit the following for discussion, which utilize existing machinery and are not inconsistent with precedents in our present legislation.

(a) That, failing agreement between a statutory electricity supply undertaker and a landowner or occupier for a wayleave for electric mains on private property, or if a landowner or occupier refuses to give a consent or fails to give a reply in writing within 1 month from the date of application, the Board of Trade be authorized, after enquiry, to make an Order for a compulsory wayleave within a further period not exceeding 2 months. In all cases the undertakers would have to satisfy the Board of Trade as to the commercial and other considerations which render this course necessary.

(b) That, failing agreement between the parties as to the annual rent to be paid by way of compensation, this be determined by one of the following methods :—

(1) By a [illegible] appointed by the Board of Trade, counsel and expert witnesses being excluded from the arbitration proceedings. The Board of Trade with the concurrence of the Lord Chancellor to be [illegible] costs unnecessarily incurred. Alternatively,

(2) By [illegible]

In fixing the wayleave rent, regard should be had to the average annual rent (if any) received from the land under [illegible] able percentage should be added to cover permanent damage, disturbance, or inconvenience which may arise from the proposed works, and for the right of entry upon the land. This percentage would obviously be greater for overhead wires than for underground cables. The arbitrator or valuer should not be allowed to take into consideration any saving in expenditure which is afforded to the undertakers by the grant of the wayleave, but should apportion the rent equitably between landowners, tenants, and occupiers, and all who have a beneficial interest in the land.

Any of the parties, failing agreement, should have the right to apply for a revision of the rent once in every 7 years. Damage to crops, etc., caused in the execution of the work should be settled separately and in the usual manner.*

(*c*) That in cases of urgency, the undertakers be authorized to enter upon the land and commence the execution of the work as soon as an Order has been made by the Board of Trade and before the assessment of the compensation, upon serving a notice, making a satisfactory deposit, and giving bond.

(*d*) That a right of appeal to the Board of Trade be allowed in all cases where a landowner or occupier demands the removal or diversion (including the placing of an overhead main underground) of a main at the cost of the undertakers which in the opinion of the undertaker is unreasonable or unnecessary.

The success or failure of any proposals such as these would obviously depend upon the degree of "public utility" which might be attached by the Government Department concerned to the various kinds of electrical services, but even if compulsory powers were only granted in important and difficult cases, the mere existence of such powers and the possibility of the grantor of a wayleave having to justify his demands would, I believe, exercise such a moral effect that in many cases an agreement would be possible without putting into operation the machinery created. It would materially assist in this very desirable consummation if undertakers were enabled to secure a declaration from the Board of Trade of the public utility of a proposed main for which wayleaves are required before negotiation is entered into with landowners and others, in all cases where the Board is satisfied that the public interest justifies such a declaration.

Suitable rules could be drawn up to preclude applications on trival grounds.

In conclusion, I regret that I have only found it possible to deal broadly with the general question of electric mains over agricultural and similar open land, and that considerations of space have not permitted the investigation in detail of other questions, such as wayleaves for the laying of electric mains, along, over, or across railway and canal lands, over and under railway bridges, and in private roads. Most of these questions, while of importance, are not so urgent as the main question dealt with in the paper, a solution for which could not fail to assist in removing other disabilities such as these.

APPENDIX I.

ITALIAN LAW FOR THE TRANSMISSION OF ELECTRIC CURRENTS TO A DISTANCE (LAW NO. 232, 7 JUNE, 1894).*

Art. 1. Every proprietor is required to permit the crossing of his lands by electrical conductors, either overhead or underground which may be required to cross the same, having permanent or only temporary right to be used for industrial purposes.

The faces towards the streets or public squares of houses, courts, gardens, orchards, and the store houses adjacent to houses are exempt from this.

Art. 2. Whoever demands such right of way must do all things necessary in making use of it and must eliminate every danger through carelessness of workmen. He may also be required to make use of work already put in hand by the proprietor and adapted to be used, compensating the proprietor for the expense that he has incurred, and contributing proportionately to the cost of maintenance.

Art. 3. Wayleaves must also be granted for the conductors to cross canals or aqueducts or other works employed for such use, provided that no impediment or diminished utility is caused to the proprietor.

Art. 4. Where it is necessary, in the route of the electrical conductors to cross public streets or rivers or streams or to touch the exterior of houses facing the streets or public squares, the special laws and regulations concerning streets and water and the directions of the competent authorities must be observed.

Art. 5. Applicants for wayleaves for electrical conductors must prove their ability to erect the same and demonstrate the value and the use of the conductors for industrial purposes; they ought, besides, to demonstrate that the wayleave requested and the manner of making use of the same is the most convenient and the least prejudicial to the lands used, having regard to the circumstances of the surrounding lands and to other conditions of the route and the place to which the electrical energy is to be conducted.

Art. 6. Before undertaking the construction of the conductors the applicant for a wayleave ought to correspond with the proprietor of the lands to be crossed, proposing an indemnity to compensate him for the diminished value of the land which will be caused by the actual work to be done and by the subsequent operation of the same. In estimating compensation the land is to be considered as it exists and without deduction for the crops it bears and with super-valuation of one-fifth. The undertaker ought also to compensate the proprietor for immediate and subsequent damage owing to the intersection of the land or other deteriorating effects, as well as for the privilege of entering upon the land for the purpose of operating and for the maintenance of the electrical conductors.

Art. 7. Where a wayleave for the conductors is requested for a period of not more than 9 years, the agreed indemnity for the value of the land will be reduced by one-half, but when this period expires, the

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* Electric Lighting Act 1882, Section 17.

* Abstract from Mr. Addenbrooke's paper. *Journal I.E.E.*, 1903, vol. 34, p. 522. For the complete text in Italian see "Transmissione Dell' Energia a mezzo Di Correnti Elettriche (Legge, Regolamenti, Dispositioni e Circolari relative)" in the Institution Library.

[illegible] wayleave can before the expiration of the term make it [illegible]

Art. 8. The undertaker must, in every case, observe that the conductors are, and must be, arranged with due regard to the legal and special regulations in regard to the matter and the special directions that are, and may be, established to regulate the working of telegraphic and telephonic communication.

Art. 9. Disputes which may arise in the application of the present law will be treated according to the usual custom, either before the magistrates or in the Courts. All the proprietors of lands on which it is desired to place conductors can be convened before one judicial authority; in this case the magistrate of the place in which the land is situated, subject to the largest contribution towards the State, will be the competent authority.

[illegible]

Art. 1. Electrical conductors for industrial use, by the law of 7 June, 1894, No. 232, are all those destined to conduct energy to a distance by means of electric currents, except telegraph and telephone conductors, which are regulated by the law of 7 April, 1892, No. 184.

Art. 2. When for the preliminary study of a projected installation of electrical conductors, it is necessary to enter upon any lands and it is not possible to obtain the consent of the proprietor, the person wishing to establish the [illegible]rs can obtain from the Royal Magistracy of the Province in which are situated the lands to be entered upon an authorization of access. He should be able to prove to the said authority the justification of the request for permission and present a demand in which are indicated:—

[illegible] study the matter.

(b) The lands to be entered.

(c) The necessary details to furnish an exact idea of the importance of the installation.

Art. 3. The magistrate, having ascertained the justification for the permission, will authorize the applicant to enter upon the lands for the purpose of studying the project, by suitable decree. In this decree the names [illegible]

Art. 4. Persons who have occasion to avail themselves [illegible] al to the proprietor of the lands, and will [illegible] suggestion of the parties, a time and method when the [illegible] railway it will be [illegible]

To assure the payment of the indemnity, the magistrate can demand the deposit of a suitable sum of money from the applicant.

Art. 6. The demand for a consent or the notification in regard to an installation is to be addressed to the Royal Magistracy of the Province, in which the installation is to be located. When the conductors cross public works or property comprised in the areas of two or more provinces, the demand for the consent or the notification is to be addressed to the Minister of Agriculture.

Art. 7. When for the working of an installation, the consent of the competent authority is wanted in the terms of Art. 5 the undertaker, besides the proof of his right to ask for a compulsory wayleave, must produce to the same authority:

(*a*) A complete drawing of the installation with particulars of the conductors and of their supports, with an indication of the crossings of the public streets, railways, rivers, streams, and canals, and with a distinction, the telegraph and telephone lines near to the projected conductors.

(*b*) A description of the installation, indicating its character, whether alternating or direct current, the maximum effective values of the differences of potential and the strength of current in the conductors, the nature and section of the same, and the system of insulation.

The applicant must also give a definite address and a period within which he undertakes to have the installation in working order.

Art. 14. [illegible] to diminish the value of the wayleave or to render it more difficult, nor to transfer the right of way to any other position than that originally fixed. The same obligation applies to the undertaker. If, however, the original arrangement has become more serious to the proprietor of the land, or if it hinders him in doing certain works, repairs or improvements, he can ask the undertaker to modify his arrangement of conductors, offering him a place equally convenient for his operations. This the undertaker must not refuse. Where the undertaker finds that a similar alteration would benefit him and no damage to the land would result, it is to be permitted.

Art. 15. The wayleave for the conductors does not convey to the undertaker the soil on either side under or over the conductors, or the relative supports, or the wall to which they may be hung. The Government taxes and other charges on the land still remain against the proprietor of the land.

Art. 18. In the cases foreseen by Art. 9 of the law of 7 June, 1894, No. 232, it is the duty of the competent authority to permit the temporary execution of work in the manner and under the conditions that are deemed necessary to meet the public requirements and the rights of the proprietors of the lands.

Art 19. The control of carrying into effect the law of 7 June, 1894, No. 232, and of the present rules, in all cases the responsibility of the undertaker, concerns the Minister of Agriculture, who will look after it, where necessary, in [illegible] information of the consents granted for the installation of electrical conductors, and of the notifications received according to Arts. 8 and 9 of the present rules.

APPENDIX 2.

Expropriation in Switzerland in the Case of Electrical Works.

Swiss Federal Law, 24 June, 1902.[*]

The following clauses extracted and briefly translated from the general law of above date relating to electrical undertakings set forth the special provisions made for expropriation.

Art. 43. The Federal Council has the right to grant powers of expropriation to the owners of electrical undertakings, as also to the consumers.

Art. 44. Branches of trees endangering the transmission lines are to be removed on demand of the undertakers, and in case of dispute as to the necessity for removal, indemnity, etc., the local authority designated by the Government of the Canton will give a final decision within 8 days. The costs of such proceedings to be to the charge of the undertakers.

Art. 45. Electrical transmission and distribution installations are defined as (1) The electrical conductors, whether aerial or underground and their accessories, and (2) Transforming stations and their accessories.

Art. 46. The right of expropriation can be exercised for private property and also for railways, but in the latter case the electrical works must not interfere with the working of the railway, and ample space must be allowed for the operation of the railway and its telegraph lines, etc. The public land and highways of the Cantons and Communes can be utilized, and rights of expropriation granted over the same for the transmission and distribution of electrical energy. When such employ of the public land of a commune for distribution of electrical energy is demanded, the commune can, to protect its own legitimate interests, refuse or restrict the demand, except in the case where the energy is required for the electrical working of a railway. The Government of the Canton can be appealed to within 20 days of such refusal or restriction, and its judgment can be further appealed against before the Federal Council within a further 20 days. The decision of the Federal Council will be final. Electrical undertakings cannot claim the use of the public land without also respecting the other uses to which the land may be applied.

Art. 47. Expropriation rights can be demanded by the undertakers of electrical installations or by consumers both for the absolute acquisition of the property or for its conditional possession whether permanently or temporarily.

Art. 48. The indemnity is to consist, according to the circumstances, of a capital sum or an annual charge. With the consent of the two parties, the indemnity can be made to include repairs for damage to crops or other damages similarly caused by alterations to the electrical constructions. If no arrangement in this respect has been made between the parties, the demands for indemnities which may be made during the working of the undertaking can, in case of dispute, be settled by the ordinary procedure.

Art. 49. Save the exceptions mentioned in Arts. 50 and 54 herewith, expropriation will take place in accordance with the provisions of the law of 1 May, 1850.[*]

Art. 50. To obtain powers of expropriation, the undertakers must address their demand to the Government Survey Department of electrical works, submitting a plan of the works and of the land required. The Federal Council will then grant expropriation rights if, within a period of 30 days from the deposit of the plans, there is no opposition. In case of opposition, rights will not be granted if the projected works can be modified without grave technical difficulties involving too great cost, or without danger to public safety. Where alterations appear necessary, a new application for expropriation rights can be proceeded with on the demand of the undertakers of the works, or of the party to be expropriated.

Art. 51. As well as depositing the plans with the Survey Department mentioned, plans are to be deposited in the communes affected, so that everyone concerned can note the same. The deposit of the plans and demand for expropriation rights shall be made public, and in addition personal notification shall be sent to everyone concerned. If expropriation is demanded for particular property owners only, the provisions of Arts. 18 and following of the Expropriation Law of 1850 will apply.

Art. 52. As soon as the Federal Council shall have given their decision and approved the plans, the Estimating Committee (Art. 54) will, if required by either party, meet and discuss the indemnity to be paid.

Art. 53. After approval of the plans, the works can be proceeded with, even though the Estimating Committee may not have finished their enquiry, or though the indemnity be not yet paid. Guarantees for such payment shall, however, be forthcoming, and in case of dispute the Estimating Committee will fix the amount of the guarantees.

Art. 54. Each Canton shall supply an Estimating Committee of three members, the Federal Court, the Federal Council, and the Government of the Canton each nominating one member and two deputies of each member.

The decisions of the Estimating Committee can be appealed against before the Federal Court in accordance with the provisions of the Expropriation Law of 1 May, 1850.

APPENDIX 3.

Extract from the United States Agricultural Appropriation Act for the Year ending 30 June, 1912, Relating to the Grant of Easements for Rights of Way for Electric Lines on National Lands.

"That the head of the department having jurisdiction over the lands be, and he hereby is, authorized and empowered, under general regulations to be fixed by him, to grant an easement for rights of way, for a period not exceeding 50 years from the date of the issuance of such grant, over, across, and upon public lands, national forests, and reservations of the United States for elec-

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[*] Extract from Mr. Addenbrooke's paper, *Journal I.E.E.*, 1905, vol. 34, p. 528. For the complete text in French see "Legislation Suisse en matières d'installations électriques," p. 20, in the Institution Library.

[*] For the complete text in French see "Legislation Suisse en matieres d'installations électriques," p. 143, in the Institution Library.

[illegible] telephone and telegraph purposes, to the extent of 20 feet on each side of the centre line of such electrical, telephone and telegraph lines and poles, to any citizen, association, or corporation of the United States, [illegible] herein granted for any one or more of the purposes [illegible] forest, military, Indian, or any other reservation only upon the approval of the chief officer of the Department under whose supervision or control such reservation falls, and upon a finding by him that the same is not incompatible with the public interest; Provided, That [illegible]

"[illegible] citizen, association, or corporation of the United States to whom there has heretofore been issued a permit for any of the purposes specified herein under any existing law, may obtain the benefit of this Act upon the same terms and conditions as shall be required of [illegible] application under the provisions of this statute."

One of the first grants under this Act was to the Great Falls Power Company of Montana for a right of way for [illegible] on the public domain. This grant was [illegible] prices approved by the Federal Government. In addition the Federal Government imposed a tax of 5 mills per 1,000 units passing over the line. The terms are subject to revision every 10 years.

APPENDIX [illegible]

[illegible]

[illegible] or under any turnpike road, or any street or place laid out as or intended for a street, or under any [illegible] giving reasonable [illegible] pier (if on the report [illegible] to through or under [illegible]

[illegible] rict for the purpose of outfall or [illegible]

[illegible]

(2) Causes any vault arch or cellar to be newly built or constructed under the carriageway of any street,

shall forfeit to the urban authority the sum of five pounds and a further sum of forty shillings for every day during which the offence is continued after written notice in this behalf from the urban authority; and the urban authority may cause any building vault arch or cellar erected or constructed in contravention of this section to be altered pulled down or otherwise dealt with as they may think fit, and may recover in a summary manner any expenses incurred by them in so doing from the offender.

Section 54.—Where a local authority supply water within their district, they shall have the same powers and be subject to the same restrictions for carrying water mains within or without their district as they have and are subject to for carrying sewers within or without their district respectively by the law for the time being in force.

APPENDIX [illegible]

[illegible]

[illegible]

[illegible]

2. (1) If the Postmaster-General considers that the inhabitants of any district or any public authority are debarred from the public convenience of telegraphic communication owing to the refusal or failure of any person being the occupier, lessee, or owner of any land or building to consent to the construction or maintenance of a work by the Postmaster-General, he may, without prejudice to any other power of proceeding under the Telegraph Acts 1863 and 1878, or this Act, apply to the Railway and Canal Commission and that Commission, if satisfied, after holding a local enquiry and giving an opportunity for all persons interested to be heard, that the inhabitants or authority are so debarred as aforesaid, may make an Order consenting to the construction or maintenance of the work, either unconditionally or subject to such pecuniary or other terms, conditions and stipulations as the Commission think just, and such consent shall have effect as a consent given by the said person to the con[illegible] aforesaid all the provisions of the Telegraph Act 1863 (26 & 27 Vict. c. 112) shall apply to such work, and such person shall have and enjoy all the protection and benefit of such provisions.

[illegible] such modifications (if any) as Parliament may approve or direct; but if such petition is not presented, or though presented is withdrawn, the Railway and Canal Commis[illegible] certificate such Order shall have full effect.

TELEGRAPH (CONSTRUCTION) ACT 1908, SECTION 4.

Extension of s. 2 of Telegraph Act 1892. 55 & 56 *Vict. c.* 59.

4. The provisions of Section 2 of the Telegraph Act, 1892, shall apply where, on the application of the Postmaster-General the Railway and Canal Commission are satisfied, that owing to the refusal or failure of any person, being the occupier, lessee, or owner of any land or building, to consent to the construction or maintenance of a work by the Postmaster-General, telegraphic communication cannot be supplied to any district or place except at unreasonable cost or on unreasonable conditions.

TELEGRAPH (CONSTRUCTION) ACT 1916, SECTION 1.

User of land and buildings for telegraphic lines.

1. If the owner, lessee, or occupier of any land or building refuses or fails to give his consent to the placing of a telegraphic line under, in, upon, over, along or across the land or building within 2 months after being required to do so by notice from the Postmaster-General, a difference shall be deemed to have arisen between the Postmaster-General, and that owner, lessee, or occupier, and Sections 3, 4, and 5 of the Telegraph Act 1878 (41 & 42 Vict. c. 76) shall apply accordingly as if it were a difference arising under the Act:

Provided that the tribunal to which the difference is referred under these sections shall not give its consent to the placing of the line unless satisfied that such refusal or failure is contrary to the public interest; and in deciding whether to give its consent or to impose any terms, conditions, or stipulations, including the carrying of any portion of the line underground, the tribunal shall, among other considerations, have regard to the effect, if any, on the amenities or value of the land of the placing of the line in the manner proposed:

Provided also that, subject as aforesaid, all the provisions of the Telegraph Act 1863 (26 & 27 Vict. c. 112), shall apply in the case of the exercise of any powers authorized to be exercised under this section, and such owner, lessee, or occupier, shall have and enjoy all the benefits of such provisions.

TELEGRAPH ACT 1878, SECTION 4.

Differences relating to a street or public road to be determined by stipendiary magistrate, county court judge, or sheriff.

4. Where any difference arises under this Act or the Telegraph Act 1863 between the Postmaster-General and any body or person having any power, jurisdiction, or control over or relating to a street or public road, or having power under the last-mentioned Act to give or withhold a consent to the placing of telegraphs and posts in, under, upon, along or across a street or public road, such difference shall in England or Wales and Ireland be referred to the police or stipendiary magistrate having jurisdiction within the district in which the difference has arisen, or if there be no such magistrate, then to the judge of the county court having jurisdiction within such district, and in Scotland to the sheriff, and such magistrate, judge, and sheriff are respectively empowered and required to hear and determine such difference, and Sections 30 to 33 both inclusive, of the Regulation of Railways Acts 1868 (31 & 32 Vict. c. 119), shall apply to every difference so referred to such magistrate, judge, or sheriff (as the case may be) in like manner as if he were an arbitrator appointed pursuant to those sections, and as if the Postmaster-General, body, or person between whom the difference has arisen were companies within the meaning of those sections.

Provided always, that in case either the Postmaster-General or the body or person between whom the difference has arisen shall be dissatisfied with the award or decision of such magistrate, judge, or sheriff, the party so dissatisfied may within 21 days after such award or decision require, by a notice in writing given to the other party, that the difference shall be referred to the Railway Commissioners.

APPENDIX 6.

The following sections of the Indian Telegraph Act 1885 relate to powers for placing telegraph lines on private land in India.

These powers have, in certain cases, been extended to electricity supply undertakers.

POWER TO PLACE TELEGRAPH LINES AND POSTS.

Power for telegraph authority to place and maintain telegraph lines and posts.

10. The telegraph authority may, from time to time, place and maintain a telegraph line under, over, along or across, and posts in or upon, any immovable property:

Provided that—

(*a*) the telegraph authority shall not exercise the powers conferred by this section except for the purposes of a telegraph established or maintained by the Government, or to be so established or maintained:

(*b*) the Government shall not acquire any right other than that of user only in the property under, over, along, across, in or upon which the telegraph authority places any telegraph line or post; and,

(*c*) except as hereinafter provided, the telegraph authority shall not exercise those powers in respect of any property vested in or under the control or management of any local authority, without the permission of that authority; and

(*d*) in the exercise of the powers conferred by this section the telegraph authority shall do as little damage as possible, and, when it has exercised those powers in respect of any property other than that referred to in Clause (*c*), shall pay full compensation to all persons interested for any damage sustained by them by reason of the exercise of those powers.

Provisions applicable to other property.

Exercise of powers conferred by Section 10, *and disputes as to compensation, in case of property other than that of a local authority.*

16. (Part only).

(1) If the exercise of the powers mentioned in Section 10 in respect of property referred to in Clause (*d*)

of that section is resisted or obstructed, the district [illegible]

[illegible] section (1), any person resists the exercise of those powers, or, having control over property, does not give [illegible]

[illegible] it shall, on application for that purpose by either of the disputing parties to the District Judge within whose jurisdiction the property is situate, be determined by him.

[illegible] *other than that of a local authority.*

[illegible]

(1) When, under the foregoing provisions of this Act, a telegraph line or post has been placed by the telegraph authority under, over, along, across, in or upon any property, not being property vested in or under the control or management of a local authority, and any person entitled to do so desires to deal with that property in such a manner as to render it necessary or convenient that the telegraph line or post should be removed to another part thereof or to a higher or lower level or altered in form, he may require the telegraph authority to remove or alter the line or post accordingly:

Provided that, if compensation has been paid under Section 10, Clause (*d*), he shall, when making the requisition, tender to the telegraph authority the amount requisite to defray the expense of the removal or alteration, or half of the amount paid as compensation, whichever may be the smaller sum.

APPENDIX [illegible]

[illegible]

The compensation to be paid for the compulsory purchase of land including damage caused by severance, and arising from the execution of the work, failing agreement [illegible] the parties, is determined by either of the following [illegible]

[illegible] the compensation is due to a tenant at will, i.e. on [illegible]

(*b*) In all other cases the amount to be paid for compensation is fixed by a jury or by arbitration at the option of the party claiming compensation [illegible] Act 1845, Sections 23, [illegible]

A person fully entitled to dispose of land may sell or convey such lands in consideration of an annual rent charge to be paid by the promoters, and persons whose power of conveyance is in doubt may also adopt this course (Lands Clauses Consolidation Act 1845, Section 10, and Lands Clauses Consolidation Acts Amendment Act 1860, Sections 1, 2, and 4).

There are no special provisions in the Lands Clauses Acts for settling compensation in connection with the compulsory acquisition of easements or wayleaves over private land, but in a few exceptional cases, e.g. in connection with the great water schemes for bringing water over long distances to large cities, special Acts of Parliament have conferred exceptional provisions to enable easements for the laying of pipes, etc., to be taken compulsorily under the Lands Clauses Acts.

These Acts contain a proviso in the following terms:—

> "Provided always that nothing herein contained shall authorize the Corporation to acquire by compulsion any such easement in any case in which the owner in his particulars of claim shall require the Corporation to acquire the lands in respect of which they have given notice to treat for the acquisition of an easement only, and every notice to treat for the acquisition of an easement shall be endorsed with notice of this proviso."

Such provisions exist in the special Acts authorizing the Corporation of Manchester to bring water from Lake Thirlmere, and the Corporation of Birmingham from Wales, also the Liverpool Corporation's Vyrnwy scheme.

The settlement of disputes in compensation cases by a jury or by arbitration is so costly, involving, as it does, the employment of counsel and expert witnesses, that public bodies often prefer to pay exorbitant prices for the purchase of land rather than take the matter to arbitration.

In the event of an arbitration, unless the parties agree upon a single arbitrator, each side must appoint an arbitrator, and the arbitrators must then agree upon and appoint an umpire before entering upon the arbitration (Lands Clauses Consolidation Act 1845, Sections 25, 27). The cost of arbitration must be borne by the promoters unless the amount awarded is the same, or less than, originally offered by the promoters (Lands Clauses Con[illegible]

This procedure is therefore impracticable in such a relatively small matter, as the ascertainment of the fair rent to be paid for a wayleave for an electric main on private property.

Parliament has already recognized the difficulties created [illegible] the Lands Clauses Acts as in some recent Acts, for instance, the Housing and Town Planning Act 1909, a local authority [illegible] Order from the Local Government Board, which requires no confirmation by Parliament, and the compensation to be

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[illegible]

paid is to be settled, failing agreement, by a single arbitrator "who shall hear by themselves or their agents, any authorities entitled to appear, and shall hear witnesses, but shall not except in such cases as the Board may otherwise direct, hear counsel or expert witnesses." Further, "The Board may, with the concurrence of the Lord Chancellor, fix a scale of costs and may disallow costs to any witness whom he considers to have been called unnecessarily, and any other costs which he considers to have been caused or incurred unnecessarily" (Housing and Town Planning Act 1909, First Schedule).

Even this procedure is, in my opinion, likely to prove too costly for wayleaves for electric mains, but I think it will bear discussion.

The following procedure allowed in certain cases by the Lands Clauses Act is worthy of notice.

It would appear from Sections 9 and 58 of the Lands Clauses Consolidation Act 1845 and Sections 2 and 4 of the Amendment Act 1860, that in cases where (*a*) the parties claiming the lands cannot be found or by reason of absence from the kingdom are prevented from treating, or (*b*) that the parties interested in the sale are not entitled to dispose of the lands absolutely, the procedure is considerably simplified, doubtless because there is no surrender of title to the land. In the former case, the compensation is determined by the valuation of a surveyor nominated by two justices, and the purchase money is deposited in a bank for the benefit of the parties interested, and in the latter case may be determined by the valuation of two surveyors, one of whom is appointed by each side, and failing agreement by a third surveyor appointed by two justices. Section 4 of the Lands Clauses Consolidation Acts Amendment Act 1860 also gives important directions in this case as to the basis of the annual rent charge by way of compensation, viz. that the annual rent charge shall in no case be less than one-fourth part greater than the net annual rent received for the lands on an average of the last seven years, and that a charge of 5 per cent on the gross sum estimated by way of compensation for permanent damage or injury to the lands shall be added to and form a part of the said rent charge.

As in the case of easements or wayleaves for electric mains, there is clearly no surrender or conveyance of title to the land, I suggest that a similar procedure might be adopted in these cases.

Finally Section 85 of the Lands Clauses Consolidation Act 1845 authorizes the promoters of the undertaking to enter upon and use the required lands before an agreement has been come to or the amount of compensation has been fixed, upon making a deposit and giving bond.

APPENDIX 8.

(*Supplied by Mr. H. M. Sayers, 17 April, 1917.*)

THE SPANISH LAW OF 23 MARCH, 1900, ON COMPULSORY WAYLEAVES FOR ELECTRIC LINES.

Art. 1. Compulsory wayleaves for electric lines created by this law cover the use of land for the installation of aerial and underground lines for the transmission of electrical energy, and for the continued maintenance thereof, subject to proper compensation to the owner of the property utilized.

Art. 2. The power to declare and decree such compulsory wayleaves lies with :—

The Minister of Fomento (i.e. Industry, Public Works, etc.), when the wayleave covers State roads and canals, public watercourses, railways, and in all cases when it affects directly or indirectly any public work, or in which the transmission lines extend to more than one province.

The Governor of the province in all other cases; but only after hearing the provincial and municipal councils if the proposed wayleave affects provincial or municipal works, respectively.

Art. 3. The petition for the concession of a compulsory wayleave must include a descriptive memorial and plan of the installation, and is to be presented to the Government Office of the province or provinces concerned. Eight days afterwards the Governor will open a public enquiry which will remain open for one month.

(NOTE.—This does not mean a public hearing, but a period within which anyone interested can deposit objections or representations in respect to the proposal.)

Within the first 10 days of the month mentioned, the enquiry will be notified in the "Official Gazette" and will be also notified to the mayors of the municipalities concerned, with the object that they shall inform the proprietors interested. Objections are to be delivered within the prescribed period to the Head Office of Public Works of the province, which shall report theron within 10 days to the Governor, who will within another 10 days either decide the matter, or will refer it to the Minister of Fomento with his report. The Governor's decision may be appealed against before the Ministry of Fomento.

To be able to require a declaration of public utility for the effects of this law, it will be necessary for the petitioner to prove title to the power to be utilized and conveyed by the transmission line.

(NOTE.—This seems to mean the right to utilize hydraulic powers which is subject to special laws and regulations.)

Art. 4. The compensation established by Art. 1 consists in the previous payment to the owner of the property by the party obtaining the wayleave of the value of the area of the land to be occupied by the posts or by the width of the trench in the case of underground lines, the value of all damage and losses caused, and the value of the right of entry necessary for the guarding, maintenance, and repair of the line; it being understood that in no case shall the value of the wayleave for the line and access thereto together exceed the just price of a strip of land two metres in width.

Art. 5. All the necessary works for the construction and maintenance of the line shall be at the expense of the party obtaining the wayleave. The land necessary for the deposit of materials may be occupied temporarily subject to the previous payment of compensation for damages so caused, or to the deposit of a sufficient sum if it is not easy to estimate this beforehand, or if the parties cannot agree upon the amount. The owners or administration can compel the concessionaire to execute the works considered necessary by the Ministry of Fomento for the avoidance of accidents.

Art. 6. The owners of the lines will be responsible by civil process for all damages caused to the properties subject to the wayleaves.

Art. 7. Anyone damaging or interfering with the lines will be [illegible] responsible as determined by the existing law.

Art. 8. [illegible] wayleaves cannot be imposed over [illegible] orchards, or kitchen gardens annexed to dwelling-houses [illegible] the time that the wayleave is decreed.

Art. 9. Neither can such wayleaves be granted over any kind of enclosed property if the owner or owners prove that there is a route by public roads contiguous thereto available for the electric lines with an increase in length not exceeding 20 per cent, or over unenclosed property if the available routes by roads, etc., do not increase the length of the lines by more than 10 per cent.

Art. 10. The concession of the wayleaves shall not prevent the owner of the property from enclosing it, or building on it, provided that the wayleaves for the line and access thereto are maintained in accordance with Art. 5. In these cases the owner will have the right to require alteration of the alignment of the line in the parts affected by the fencing, etc., or the building, subject to Art. 8 of this law.

Art. 11. Wayleaves will cease to have effect if not made use of during nine years, which period shall be reckoned from the date on which the owner received the compensation paid according to Art. 4.

Art. 12. Compulsory wayleaves for lines within populous places will be regulated by the general and local urban police ordinances, and so far as not provided for by those ordinances, by the precepts of the Civil Code.

Art. 13. The Ministry of Fomento will prescribe the regulations for the accomplishment of this law.

Royal Assent, 23 March, 1900.

[illegible]

Art. 3. To obtain the benefit of the law of compulsory wayleaves for electric lines, undertakings must have been declared of public utility by the Administration, and will be subject to all the relevant conditions established by these regulations.

Art. 4. Undertakings for private use only, if they occupy positions subject to governmental service—whether State, Provincial, or Municipal—or public lands, and requiring for such occupation special regulations, will be subject so far as such occupation is concerned to these regulations.

[illegible] refers to electric lines over or under streets, roads, etc., belonging to undertakings which are not entitled to compulsory wayleaves.)

Art. 5. The undertakings referred to in Art. 4 require special concession to authorize their use of the public ways [illegible]

Art. 6. Undertakings affecting military, industrial, mining, and State service zones will be subject to the special [illegible]

Art. 7. [illegible] articles will be declared and decreed in virtue of administrative process with the information and procedure laid down in these regulations, and subject to the general conditions thereof as well as to special conditions required by the circumstances of each case.

[illegible]

Art. 8 repeats the provisions of Art. 2 of the law as to the authorities having power to grant concessions, adding that the same authorities will have power to sanction further alterations.

Art. 9. Permits the division of the process into parts coming under one or the other of the authorities named, to facilitate the obtaining of consents to future alterations by reference only to the one concerned.

Art. 10. The petitioner is to present the request for a concession to the Governor of the province in which the energy is to be produced or whence the transmission starts. When compulsory wayleaves are required the petitioner must prove his title to the power to be utilized, and must deliver a list of all the private properties to be traversed by the lines, and of their owners. If the process is divided as provided in Art. 9, the necessary lists, etc., must be made out separately for each part.

Art. 11. Besides the list of properties and owners, the following documents must accompany the petition :—

1. A description of the system, its ownership, voltage, and the object of the undertaking, the insulation and resistance of the underground or aerial conductors, their position with reference to other lines crossed or within the range of their influence, with special mention of telegraph and telephone lines, and submarine cables, within 25 metres thereof, as well as the proposed methods of crossing and occupation of public ways and lands.

2. A general plan and section showing the properties affected, detailed plans of the parts near dwellings, public ways and lands ; for underground lines the position of pipes, etc., existing on the route, and for aerial lines the existing aerial lines within 25 metres of the proposed [illegible]

3. An estimate of the amount of public lands to be occupied, and if the undertaking is for public supply, a statement of the tariffs to be adopted and the other data required by Cap. 8 of the regulations of the general law of Public Works of 1 July, 1877, so far as it relates to concessions affecting public and State property.

Art. 12. The date and hour of the delivery of these documents will be recorded ; at the end of three days they will be sent to the Chief Engineer of Public Works, who in a further six days will report whether they are or are not sufficient to serve as the basis of the process, and in the latter case will return the documents for amendment [illegible] appeal to the General Direction of Public Works if he does not accept the Governor's decision, based on the report of the Chief Engineer.

(Note.—The Chief Engineer referred to is the Provincial Chief Engineer to the Department of Public Works, and the General Direction of Public Works is the Head Authority of that sub-department at the Ministry of Fomento in Madrid.)

Art. 13. If declared sufficient, the Governor at the end of three days after receipt of the Chief Engineer's report, will publish the application, etc., in the "Official Gazette" of the Province, and will open a public enquiry for 30 days, within which time the objections of interested parties can be received. If other Provinces are affected the respective Governors are to be advised and are to publish the notice in the same way. The published notice is to be sent to the Mayors of the districts affected who are to display them in the usual places for public announcements during 30 days, and are also to inform the owners of the properties over which it is proposed to take compulsory wayleaves. Objections are to be presented within the period named at the Chief Office of Public Works in the Province, and similarly the Mayors at the end of the period will remit thereto certificates that they have made the publications and notifications required, and will also report on the projects so far as they affect municipal services. The objections will be notified to the petitioner within three days, who will then have 10 days in which to answer them, or to accept them, and alter his proposals accordingly, as he may consider proper.

Art. 14. If the proposals affect State works and services of other Departments than the Ministry of Fomento, or of the Provincial Governments, the chiefs of such Departments, etc., are to be advised and to report within 10 days, with any proposals which they think necessary for the protection of their respective services. To save time the petitioner may furnish special or duplicate documents for consideration by these Departments at the same time as the public enquiry is proceeding.

Art. 15. The whole of the documents and reports and the reply of the petitioner will then pass to the Chief Engineer who will report upon the whole matter within 10 days, unless he finds it necessary to inspect the locality. In the latter case he will within three days advise the Governor accordingly with an estimate of the cost of the inspection, of which the petitioner will be advised. When the amount has been paid in, the Engineer will either himself or by deputy make the inspection within a period of 30 days. This period may be extended by the Governor up to a maximum of 60 days, or further by special authority of the Minister of Fomento for due cause shown.

Art. 16. The Governor after hearing the opinion of the Provincial Council, which shall report within 10 days, will give his decision within an equal period if the concession is within his powers; and if it is beyond his jurisdiction, he will refer it with his report to the Minister of Agriculture, Industry, Commerce, and Public Works, to whom, in any case, an appeal shall lie against the decision of the Governor.

Art. 17. Provides for cases affecting more than one Province that there shall be a similar notification, etc., in each, the Governor of the Province in which the energy is to be generated acting as the originator of the notices, etc., and having to collect all the documents from the other Provinces as well as from his own, and to remit them conjointly to the Ministry.

Art. 18. Prescribes the procedure for undertakings referred to in Art. 4 not requiring compulsory wayleaves.

Art. 19. Provides that a deposit of 1 per cent of the estimated cost of the works affecting public property is to be made by the petitioner with the petition, which is to be made up to 3 per cent after receiving the concession and before commencing any work on such property. This deposit is subject to any claims; first for any damage done to public property; secondly to pipes and other property belonging to other parties on such property, but the petitioner will be liable to the State and to such other owners for any damage in excess of the amount of the deposit, by civil process. The deposit will be returned at the conclusion of the works properly executed, if no claims have been made upon it, against the certificates to that effect of the Mayors of the districts.

Art. 20. Repeats the provisions of the compensation payable for the wayleave.

(NOTE.—The procedure for determining the amount of compensation is not set out in these regulations. It is referred to as the "just price" (*justiprecio*), and is determined under the provisions of the general law for assessing the compensation for compulsory expropriations, easements, etc.)

Arts. 22–26. Repeats the provisions of the law as to buildings, enclosed property, etc., in relation to compulsory wayleaves.

(NOTE.—In reference to "enclosed property," very little agricultural land in Spain is enclosed in any way.)

SPANISH LAW OF COMPULSORY EXPROPRIATION.

(Abstract of the procedure of valuation of property taken for works declared to be of public utility.)

The declaration of "public utility" has to be made by the Ministry interested in the case of works affecting more than one province; or by the Governor of the province if only that one is affected. The works which may be so declared include any works which result in public benefit, whether executed by a governing authority or by duly authorized companies or private firms. If so declared by the terms of the law or other document authorizing the works, a special declaration by the Ministry or Governor is not necessary.

The declaration of public utility has to be notified by the "Official Gazette" of the province concerned, and by communications addressed to the authorities of the localities in which property has to be acquired.

The company or person authorized to carry out the work has to deposit plans, etc., of the properties affected, showing how much of each is necessary for the works, with the Governor of the province, which plans are then sent to the local authorities for checking as to the names of proprietors, etc.

After this checking the Governor announces through the "Official Gazette" a period within which all persons interested may make representations against the expropriation proposals. After consideration of these and consulting the Provisional Council, the Governor decides in each case whether the expropriation is necessary for the intended works, and may reduce the area of any parcel of property.

The land, etc., to be expropriated is measured conjointly by representatives of the owner and the party authorized to carry out the work. This agreed measurement is the basis of the valuation.

The two parties then have to try to come to an agreement on the price to be paid. The process is that the authorized undertaker forwards through the Provincial Governor his offer to each of the owners, who have either to accept it unconditionally or to refuse it within 30 days. If accepted the undertaker may at once pay the price and take possession of the property.

If the owner refuses the offer he has to present his own expert's valuation of the property to be acquired. The undertaker then has to nominate an expert who has to make an independent valuation and send it to the Governor. If either of these valuations agrees with the original offer of the undertaker, this price is taken and reckoned as the agreed price.

In the case of disagreement, the Judge of the district is then required to nominate a third expert, whose valuation is final. It is provided that this final valuation must lie between those of the experts acting for the undertaker and the owner.

It is also provided that the owner shall receive 3 per cent above the just price for expropriation.

Strictly, the final determination of the price to be paid to each owner is fixed by the Governor, after consulting the Provincial Council. The limit of his discretion in this matter is that the price shall be between the valuations of the buyer's and seller's experts. His decision is, however, subject to appeal to the Ministry concerned, and appeal may also be made to the Courts on the ground of alleged informality in the procedure, or on the ground of unfair valuation amounting to at least one-sixth part of the true value alleged by the owner.

The valuation procedure in the case of disagreement may therefore be said to be effected by two experts and a single arbitrator, also an expert, but with some power of revision by the Governor. Also all the proceedings take place under the jurisdiction of the Governor presumably as a safeguard that all the formalities are observed. These formalities include time limits for the action of each party at each stage. The Arbitrator, for example, has to give his decision within 30 days of the submission.

The payment of the compensation has to be made through the local authority at a given day and hour, properly advertised.

It will be noted that under the electric line wayleave law, the maximum amount of land to be taken and paid for for wayleave purposes is defined as a width of two metres, which includes the wayleave for maintenance, etc. Annual rent payments do not seem to be contemplated in the expropriation law.

There is no definition of "just price" in the available statement of the law. This is probably defined in the Spanish Civil Code.

DISCUSSION BEFORE THE INSTITUTION, 12 APRIL, 1917.

Mr. Wordingham.

Mr. C. H. **WORDINGHAM** : The paper appears to be very fair. It is clearly essential to the success of large power undertakings that their overhead mains, and also their underground mains, should be taken by the most direct routes possible. It is also of prime importance that no existing rights should be unduly interfered with, whether those rights be the rights of local authorities, who are the stewards of private individuals collectively constituting the public, or whether they be those of private individuals who have invested their capital or inherited property which they wish to put to other uses than the accommodation of mains. The outstanding feature of this question is, I think, that any action taken should be solely directed towards conserving those rights. Unfortunately, in many instances, as has been pointed out by the author and is a common knowledge, safeguards which have been afforded to individuals and public authorities have been employed in the most iniquitous manner to obtain advantages to which they [illegible] could not have been contemplated when powers were given by Parliament for conserving their just rights. It is clear, therefore, that the course proposed by the author is the correct one, namely, that there should be an appeal to some competent tribunal by any party affected by a supply undertaking wishing to lay mains; that the supply authority should be heard, and that the objecting public authority or private individual should also be heard. The matter should be adjudicated upon by that tribunal which, as indicated in the paper, should be composed of persons having judicial functions, accustomed to weighing evidence and giving decisions thereon, aided by expert advisers whose only object is to guide them correctly in the matter, that is to say, not employed to make as good a case as they can for one side or the other, but to advise on the technical points involved those who are giving the decision.

Mr. Wo ingham

Colonel Ogilvie

Colonel A. M. **OGILVIE** : This paper comes at an opportune time, because it calls attention to what is certainly a crying evil in the electrical industry, and one which requires more than ever to be remedied in view of the large development of the industry which must follow the War. I believe that when the time comes for legislation, Parliament and the public will be found to be much more conciliatory and reasonable than at any previous time before the War. I say that because Parliament last year for the first time granted the Post Office wayleaves over private property, and the fairly comprehensive Bill which we presented passed without unreasonable opposition. The author in dealing with the question of wayleaves over private property, which for power lines are probably more important than wayleaves on highways, refers to what he calls the satisfactory statutory powers which are obtainable by power enterprises under the Electric Lighting Act. I myself should not regard those powers as satisfactory, for, as the author shows, in some respects the undertaking which has statutory powers is in a worse position than a private enterprise or person without statutory powers. Such a person is in an equally good position to obtain wayleaves over private property as the company with statutory powers, since both have to depend entirely on negotiation with the owner of the property ; but when it comes to carrying a line across a road so long as he does not interfere with the use of the road as a road, the private person is not restricted in regard to suspending wires over the roadway, whereas the body with statutory powers cannot suspend its wires over the roadway, even without an attachment, unless it obtains the consent of the lonel ilvie. local authority, which may impose unreasonable conditions against which there is, apparently, no appeal. From the Post Office point of view wayleaves on roads are more important than wayleaves on private property, because for many reasons it is on the whole better to put telegraph and telephone lines along public roads. Therefore we attach great importance to such wayleaves, and we have suffered in the past, and still do suffer, great inconvenience and loss from the difficulties which we experience in dealing with public authorities. This country has a very large number of different local authorities who are road authorities, all of whom have to be consulted, and who are guided by advisers with very varying knowledge of the law, and very varying ideas of the reasons for which Parliament has required their consent to be obtained, and of their reasonable rights in fixing conditions. These difficulties apply equally to undertakers who require to run power wires along roads, and I should certainly say that there is a strong case for legislation in that respect, as well as for legislation with regard to powers over private property. With regard to the proposal for legislation for powers over private property, I do not think there can be any two opinions as to the reasonableness of the claim put forward by the author. It is certainly a necessity of the future that we should have some organization which can determine the conditions on which statutory rights over private property can be exercised. In conclusion, I should like to make one suggestion, namely, that at all costs it would be better to avoid any system which would put the determination of the conditions in the hands of individual arbitrators appointed from time to time and assisted by expert surveyors, or assistants who might be expert in property valuations, but who, like the arbitrators, would generally be unfamiliar with the particular conditions applying to cases of this kind. Our experience in the Post Office is that individual arbitrators as well as stipendiary magistrates and county court judges, although they give very careful consideration to the evidence put before them, vary extremely in their point of view, and as a consequence we are sometimes subjected to eccentric and difficult decisions. The Post Office have fortunately a right of appeal to the Railway Commissioners; and certainly from our own experience we should always prefer to deal with a regularly constituted judicial body of that nature, which has an accumulated and comprehensive knowledge of the conditions, circumstances, and considerations to be taken into account in dealing with wayleave applications.

odhouse. Mr. W. B. Woodhouse: The author has put on record not merely what we desire for the future, but also the history of the past. The history of the past is not a happy one. The legislation affecting supply is quite antiquated and does not give us the freedom that we feel we should have, but, to get it altered, we must make out a very strong case for the future needs. The author gives a number of reasons why we should be permitted to obtain compulsory wayleaves, and I think I might add one or two other reasons. In the first place, in very many districts underground cables are unsafe to use because the districts are undermined and there is frequently a heavy subsidence; in such districts a case can be made out for overhead lines solely on the grounds of security of supply. Next we shall have to consider the use of very much higher pressures than those at present in vogue, and, accompanying those high pressures, the transmission of very large amounts of power by parallel routes for some distance from the power stations. The power needs of the agricultural districts of the country can be supplied by overhead lines, in fact it is practically the only way in which one can attempt to deal with that demand. Then there is the very important question of railway electrification. If that is to be done on a general scale we shall need still further wayleaves, and unless we can be sure of obtaining all these wayleaves on reasonable terms and with a reasonable security of tenure the development of power supply will suffer. The most valuable precedent of the Post Office Act of last year must not, I think, be lost sight of. It is not claiming too much to say that the national needs for electrical power are as great as the national needs for the telephone and the telegraph service. Dealing with the history of the subject, I should like the author to add to the references which he has given, a reference to the report of the Joint Committee of the two Houses of Parliament which sat under the presidency of Lord Cross in 1898. In that Report reference is made to the necessity for increased facilities for wayleaves, not only for wires and cables, but for pipes, etc., in connection with power stations. It was a very important recommendation, but unfortunately it has not been acted on. The Council of the Institution in 1902 also made some valuable recommendations which deserve fuller notice (Resolutions of the Committee on Electrical Legislation 1902). In one portion of the paper, in dealing with the consents of local authorities, the author rather suggests that we should distinguish between the district of a county borough and that of an urban district council. I do not think that is wise, or a reasonable distinction. The constitution of the local authority has nothing to do with the nature of the country over which one may want to take overhead lines. I know of several cases of high-pressure overhead lines in county boroughs, but they are just as much in the country as if they were in the area of a parish council. The suitability of the district for overhead lines should undoubtedly be determined by some tribunal sitting locally, which could go and inspect the land and see what it was like. In dealing with wayleaves, the author has mentioned several interesting cases of difficulties that have been met with. It is good to have those difficulties put on record. One difficulty that I have met with, which I do not think the author has mentioned, is that of dealing with wayleaves on land coming under the Settled Lands Act, by the provisions of which, apparently, it is impossible to grant a wayleave for a longer period than 21 years. I think if legislation is to be framed to give us fuller powers that point might be dealt with, as length of tenure is most important. Again, in dealing with lands which are in the hands of trusts or executors, much legal work and an appeal to the Courts is frequently involved. I know of one case in which the legal expenses to obtain a wayleave from a trust for about two miles of mains amounted to very nearly £100. That is a heavy tax on an overhead line. Legal expenses generally are heavy. Naturally the company which wants to get the wayleave has to pay the legal expenses, and quite a business has grown up among certain persons of seeing how much they can get out of the public supply authority in that way. The terms which local authorities desire to impose when [illegible] n amount of consideration, not only by [illegible] affected. The supply authorities, both municipal and company, have felt very keenly about the subject, and a great deal of work has been done by them. I know the matter [illegible] with electrical matters, and I trust it will receive the attention of the Board of Trade Committee that is now sitting. I feel that it will help matters for[illegible] that we support in principle all the recommendations which the author has made, though of course the details may want considering a little more fully.

Mr. D. A. Starr : I am pleased to say that in Scotland, and particularly in the area worked by the undertaking with which I am connected, there are not so many obstacles put in our way as instanced in the paper. The [illegible] s and the local authorities, who are really [illegible] ty councils, composed mostly of reasonable business men and advised by level-headed road surveyors. We have many miles of overhead transmission, all of which is on private ground. The work of negotiating [illegible] a [illegible] partment, under the guidance of a skilled land valuator, has been created to deal with it. This department negotiates all wayleaves and adjusts contingent claims relative thereto. Referring to that part of the paper under the head of "Consents," as already stated we have very little trouble now with the local authorities. The Board of Trade deals with these matters in a progressive and public-spirited manner, and the regulations imposed are not onerous. So long as we conform to their Model Regulations we are assured of their consent, and in [illegible] We [illegible] nstrating fully to the satisfac[illegible] that overhead crossings are not [illegible] if constructed in accordance with B.o.T. Model [illegible] s, and they generally advise the county councils [illegible] ly. In Part 2 of the paper under the heading of "Wayleaves" the author deals almost entirely with wayleaves required over agricultural and open uncultivated [illegible] not refer to the question of private [illegible] and to merit prompt redress, and the [illegible] sted in the local authorities as in [illegible] existing railway, and the railway companies in Scotland either fix a nominal annual rental, in order to preserve their rights, or in many cases charge a rental at a given rate per mile, and a rate per 1,000 units passed over the cable per mile per annum. All wayleaves over private property have naturally to be paid for, but the annual rental demanded by some landowners is simply extortion. Fortunately, we have had very few examples of this in Scotland. We have, however, had to alter routes on several occasions. Under the wayleave department which we have organized, the work of arranging wayleaves has been reduced to an established routine. First a plan is prepared showing the entire line of route with the boundaries or the particular estate indicated and all pole positions given. This is forwarded to the estate agent with a letter of application containing a brief account of the work, the objective of the line, and all information requisite to enable the landowner to form an opinion as [illegible] Model conditions and rates are as follows :—(1) For overhead work 1s. per pole standard per annum. (2) Cables laid solid 1d. per lineal yard per annum. (3) Obligation to remove cables on receiving 6 months' notice in writing. (4) To free and relieve the proprietor of the lands in question and his tenants of all liability for any loss or injury he or they may sustain by reason of the presence of the said overhead line or cables, or by the laying, maintaining, or removal thereof. (5) To settle all reasonable claims for surface damages sustained by the tenants in consequence of the erection and maintenance of said poles or the laying of such cables. The plan is ultimately embodied with a minute of agreement between the parties. At the same time negotiations are opened with the agricultural tenants, and their consent and possibly active support enlisted. Some of the most progressive farmers welcome these lines as offering the prospect of power supply, and in many cases this is provided at a nominal charge and sometimes as a set-off against surface-damage claims. The farmers' supplies are given from pole transformers and in every case have proved mutually successful. The rental under the tenant's lease from the landowner is on an average about 40s. per acre per annum. Assuming that a standard "A" pole occupies a space of 2 square yards, then a payment of 1s. per pole standard to the ground superior is equivalent to a payment of £120 per acre. The figure of 1d. per lineal yard for underground cables (which are no detriment to the land once they are laid) gives the proprietor a much better return, and on the same basis should not exceed 0·15d. per yard. The compensation to the tenant varies and depends entirely upon the actual damage sustained by the tenant. First we ascertain the actual damage due to the construction of the line, and this is paid at once, then an annual payment is made in accordance with the damage actually done in maintaining and patrolling of the lines. This may vary from year to year, depending upon how much work is necessitated. I have referred to the methods adopted by my concern, as I understand that we are in a much better position than some of our colleagues in the South. The three examples given in the paper showing the difficulties of arranging [illegible] remedial measures should be taken at once, and I agree that it is essential that a right of appeal to the Board of

Mr. Starr

. Starr. Trade should be allowed in all cases. Questions regarding amenities by either landowners or tenants should be left to independent arbiters. Some such arrangement as is made in certain States of the United States should certainly be put in operation in this country. In Canada, and particularly in the province of Ontario, land can be expropriated by a public utility company, and the compensation if not mutually arranged is adjusted by arbitration. The fact of such legislation being in force, however, has a beneficial effect on any such negotiations, and in many cases arbitration is unnecessary. I think it is very important that prompt action should be taken in this matter, and I hope that the proper machinery will be put in operation at the earliest possible date for bringing this matter to the attention of the powers that be. In the proposed Supply of Electricity Bill the subject of wayleaves as covered by several sections is fairly fully dealt with, and should this Bill become law, a great many of the present difficulties should disappear.

. Stubbs Mr. A. J. Stubbs: As regards legislation, although the Post Office engineer would watch the Postmaster-General's rights in connection with any legislation proposed in behalf of the power authorities, the Post Office engineer and the power engineer are brothers-in-arms in this matter, and should be in a position to help each other. Although the Post Office now is not in an ideal position, it is in a better position than the power engineer. I therefore suggest that legislation might advantageously take the form of a short Bill conferring upon power engineers the wayleave privileges of the Telegraph Acts in regard to private property. The arguments might be of this character :—(1) The privileges of the Post Office have not proved oppressive to private owners; (2) they have proved distinctly advantageous to the community; (3) it would be an appreciable convenience if all electricity undertakings had practically the same legal status and the same procedure; (4) further legislation for either authority could be definitely extended to or withheld from the other. This would carry with it appeal to the Railway Commission, whereas the author assumes that the appeal of the power engineer would be to the Board of Trade. The position of the Board of Trade, however, in regard to power undertakings is something like that of the Engineering Headquarters of the Post Office in regard to telegraphs; that is, the Board originates or controls the general arrangements of the system; and it would be somewhat undesirable to make it also a court of appeal. On the other hand, if the procedure for power undertakings were assimilated to that for telegraphs, the Board of Trade would give moral support to the power undertaker; or, as a last resource, could agree to and even support an appeal before the Railway Commission. The individual power undertaker would thus have the advantage of the advice of an authority with a wide experience of the business.

igham. Mr. J. C. Wigham: The first point that occurs to me is: why should either the local authority or the Board of Trade have the right to forbid statutory undertakings to put their lines overhead since they cannot forbid the private owner to do so? The original reason is a matter of history and these restrictions ought now to be entirely removed. The most important question in connection with wayleaves arises under two heads: first, the decision whether it is reasonable and proper that a certain line should be run; and secondly, the compensation that ought to be paid to the private owner whose property is being appropriated for the purpose. Those two points ought to be kept distinct. The first is a technical point dealing with the development of electricity supply undertakings and requires consideration by technical men. The second point is one that interferes with the liberty of the subject, and therefore comes in quite a different category. Various suggestions have been made for dealing with the matter. Mr. Stubbs suggests that power engineers should have the same rights that the Post Office possess. I am sure we should be very pleased to have them, but I do not think there is much chance of Parliament giving power engineers what they have given the Post Office—the right to run a power line on any selected route. The author has given some very useful and interesting information by gathering together the various regulations in force in foreign countries, and the various suggestions that have been made for dealing with the question in this country. He first deals with the Land Enquiry Committee's report, where they recommend that a Government Department shall say that the scheme should be carried out, but that a judicial body with judicial functions should be employed for the purpose of assessing the compensations to be paid. The author's suggestion at the end of the paper is to put both of these powers in the hands of the Board of Trade: the executive power and also the decision in regard to compensation which is to be made by a single arbitrator appointed by the Board of Trade. In the draft Supply of Electricity Bill, which was prepared during the past 12 months by the Incorporated Association of Electric Power Companies and the Incorporated Municipal Electrical Association, the two questions of the withholding of consents and the granting of wayleaves have been very carefully gone into, details being given as to the regulations which would be employed and so forth. In this case, again, the power of deciding whether the lines should be run was given to the Board of Trade, who were also to appoint the arbitrator to deal with the matter of compensation. One useful point which is made in the draft Bill is that all questions connected with compensation should be determined by the same arbitrator sitting continuously, because it is only the man who is continually dealing with questions of wayleaves who can be expected to be able to form a fair judgment as to the compensation which should be paid; otherwise we should have compensation granted at the rate of £1 a pole in one district and 1s. a pole in another. Many of us at present have to pay rent within those wide limits. Finally, it has recently been suggested that a judicial Electricity Commission, something on the lines of the Railway Commission or the proposed Judicial Land Committee referred to in the paper, should be established, and here I think we have the idea of a judicial body of the right kind to decide judicial points when dealing with such questions. The point I wish to make is that a technical body should decide the technical questions as to where the line is to be run; but when it comes to the question of compensation and a decision as to the disturbance of private property or the overriding of private rights, it should be a matter for a judicial body and not for an arbitrator appointed by a Government department.

[illegible] view of this subject [illegible] benefit which I think at present they hardly realize; and if they could only get a big demand for Home trade, they would be placed in a very much better position for dealing with foreign trade in competition with other countries. The author states on page 329 that he thinks the time has come to *consider* seriously whether the important services which public suppliers of electrical power afford do not call for prompt legislative assistance. I submit that the time has come to *act*. Then he says that we have every reason to *expect* that the electrical services will be dealt with. I feel that, in the interests of the country, we have every reason to *demand* that the subject of electricity supply shall receive the consideration due to it. It has been a surprise to me to notice how absolutely [illegible] for wayleaves. A member has supplied me with a statement of actual cases of difficulties in getting wayleaves. In one column showing the great discrepancy in the charges demanded for these rights, I find that the rates paid [illegible] and last, but not least, £26,000. I think this shows that there is something radically wrong somewhere. It is not so important in connection with the past, but it is of vital importance for the future if the electricity supply of the country is to be developed. We must get these questions settled that are stopping its progress. I believe that the Defence of the Realm Act has even had to be resorted to in order to obtain wayleaves for a supply to munition works. This proves that some powers are required different from those which at present exist. In the third paragraph of the right-hand column on page 331 I suggest that the words "or Electricity Board" be inserted after the words "Board of Trade." Reference is made on page 332 to parks and commons. If we get these powers for overhead lines it is imperative that we should consider the neighbourhood, and that we should do nothing whatever to disfigure it. Provided we act reasonably in using these powers I do not think we shall have any opposition. Several speakers have referred to a point raised on page 334, in connection with which I think we have an [illegible] I suggest that paragraph (*b*) at the [illegible] Board of Trade or Electricity Board is empowered to authorize the laying down or erecting of power lines on private land." Seeing that the Post Office has already got [illegible] Why cannot we get these powers? It is because [illegible] tant that electricity supply shall be represented [illegible] concrete form by a recognized public or [illegible] dy. The recommendations of the Land [illegible] mittee referred to on page 335 are so very [illegible] mittee's report should be referred to in making any representations to the recognized authorities. In their report I suggest the insertion of the words "Electricity Board" instead of the words "permanent tribunal." If such powers were given, the vast majority of cases would in my opinion be settled by such a Board, and only in exceptional instances would it be necessary to appeal to a higher authority. I feel that electricity supply has for many years been working against the legal tide, but there is much evidence that the tide is turning or has turned, and if we can only get this Board appointed we shall be carried on to achievements which we do not realize at present. Now is the time. It is no use talking about "after the War." Questions connected with agriculture, fuel, and power factories are in the air. There will be such a vast amount of legislation after the War that Parliament will be unable to cope with it all, whereas I believe that at the present time we can make rapid progress in connection with what may be called semi-War questions. I would make an earnest plea that we should co-ordinate all these problems in such a Board as I have suggested. Why deal in one way with wayleaves and in other way with another subject, and so have constant disputes?

Mr. Kingsbury

Mr. J. E. Kingsbury: I should like the members to consider what can be done to accelerate any action that can be taken in regard to this matter. The author concludes his paper with proposals which we all recognize as perfectly sound and necessary, and the only question is: When can such proposals be carried into effect? Colonel Ogilvie said that last year the Post Office received certain powers. I notice that a Parliamentary Committee recommended in substance that those powers should be granted in 1885. If it takes 30 years for a proposal made by a Parliamentary Committee to be carried into effect, how long would it take for a proposal put forward by this Institution to go through Parliament? I am sure that we shall not carry any measure through Parliament unless the public is prepared to receive that measure as a fair and proper one. What we are suffering from unquestionably in connection with this question of wayleaves is the lack of public information and public appreciation of what it means if a householder or landowner adopts a dog-in-the-manger policy, and either refuses to give permission at all, or gives permission only on exceptional and onerous terms. If the author desires to add to the historic records in the paper anything outside Acts of Parliament, I suggest that the report of the Committee which sat in 1885 should receive some attention. The drawbacks of withholding consents are clearly stated in that report. Once the public realize that what they are doing is standing in the way of progress when a refusal is given to the running of a wayleave, and that something is being withheld from the community, I think there will be a gradual appreciation of the real facts of the case, and that they will look at it in a different manner from simply a matter of pounds, shillings, and pence. The [illegible] that in seeking to maintain their rights they are doing a serious injury to their fellows. Let them understand that they are doing that injury; let Parliament understand it, and then I think something may be done to produce that state of mind and information which will enable the pro-

r. ingsbury. posals that the author has made to be carried into effect before 30 years have elapsed.

r. Sayers. Mr. H. M. Sayers: The author speaks with some doubt as to the legal position in Spain. I obtained some little time ago copies of the laws and regulations relating to wayleaves for electric lines in Spain, and I find that substantially the Spanish law follows the Italian law. Compulsory wayleaves created by that law include the use of land for the installation of aerial and underground lines for the transmission of electrical energy, and for the continued maintenance thereof on freehold terms, subject to proper compensation to the owner of the property utilized. The application of these general powers depends upon the work being declared to be of public utility, as in the Italian case. The determination of compensation is by the application of the general law for expropriation, which has been in force in Spain for a very long time, particularly for irrigation purposes, roads, and other purposes of declared public utility. I do not propose to read a synopsis of those laws and regulations, but as they have some points of difference from the Italian and French law, and as they do not appear to have been previously published in the *Journal*, I will send in a translation (see Appendix 8 on page 343.

r. Sparks. Mr. C. P. Sparks: I should like to say a few words first of all with regard to the reason for a paper on this subject being read before the Institution. The Council have taken and are taking a great interest in the question of electricity supply: they have appointed a committee to report to them on electricity supply, and this paper has resulted as part of the work of that committee. While it is generally recognized that the future of our electricity supply is closely connected with the erection of what are known as super power-stations, the question of the outlet for those stations is so intimately connected with necessary modifications of legislation that it was thought advisable that a member fully competent to deal with the matter should lay the whole of the history of the subject before the Institution in order to secure the desired publicity. To-night the discussion has been a very one-sided one; there has been no criticism at all of the proposals contained in the paper; on the contrary all the speakers have been in favour of them. Perhaps as President I may be permitted to say, in the way of advance information, that the Council to-day, when considering the award of the annual premiums, selected this paper, although it had not been read, as one which should be recognized as possessing outstanding merit, and they have recommended that the author be awarded the Paris Premium. I wish also to say something with regard to the paper itself, particularly on one point referred to by Colonel Ogilvie, namely, the respective positions of a statutory and a non-statutory company. In the present state of the law there is no doubt that a non-statutory company is in a stronger position than a statutory one. I remember in the case of a large non-statutory undertaking which erected a 10-mile transmission main operating at 30,000 volts, which I described in a paper read before the Institution, the question of negotiating the wayleaves arose, and in that instance we were able to secure the desired wayleaves with a minimum of trouble. If a non-statutory company desires to cross the highway with its overhead mains the local authority cannot refuse permission, although if it desired to run its mains along the highway it would be a matter of negotiation. But the local authority cannot prevent a crossing. As far as property owners are concerned, we were free agents in our right of negotiation with them. In this particular instance we were dealing with coal, and the landowners being largely interested in the prosperity of the coal-mining industry would not think of interfering with us. But a statutory company is in a different position. Then with reference to the attitude of the railway companies, it must be borne in mind that in the particular case to which I am referring the output of coal was between 4 million and 5 million tons a year. There were alternative ways of transporting the coal, and a railway company which perhaps is dealing with 1½ or 2 million tons of coal a year from one undertaking cannot refuse to grant facilities, in fact they are only too pleased to do so. If they did not, it might mean the diversion of traffic to some other line. Even the Post Office are flexible when dealing with a non-statutory company. Part of their works were situated on our land, and this helped to secure reasonable facilities for our erecting transmission lines in the neighbourhood of their wires. There is one further point I should like to mention in connection with the question of compulsory wayleaves. It will be seen from the paper that Italy secured compulsory powers in 1894, Switzerland in 1902, and the United States in 1912. We have heard Mr. Kingsbury's somewhat pessimistic estimate of the time it will take us to get an Act of Parliament passed. But I am sufficiently of an optimist to suggest that we shall have these powers within the next two years. The necessity for the conservation of fuel is being more and more brought home; this factor and the prime necessity for cheap power will force on the legislature the necessity for granting powers to secure wayleaves. I believe that within the next two years we shall have not only the powers indicated in the paper enabling us to use super-stations, but also many other powers that are necessary to allow electricity to play its fair share in the general economy of our nation. Mr. Sparks.

Mr. W. A. Chamen (*communicated*): As Chairman of the Joint Committee of the Incorporated Association of Electric Power Companies and the Incorporated Municipal Electrical Association appointed for the purpose of drafting a Bill which it is hoped may be presented to Parliament at the earliest opportunity, I may say the question of wayleaves has engaged the attention of that Committee to a very considerable extent and the following clause (No. 11) appears in the draft Bill:— Mr. Chamen.

11. The undertakers may within their area of supply or any extension thereof under Section 6 of the Electric Lighting Act 1909 or otherwise construct maintain repair alter and remove electric lines either over ground or under ground across over or under private property or common lands, rivers, railways, canals, tramways, aerial ropeways, pipelines, water channels, and the like, subject to the consent of the owners thereof, or without such consent (notwithstanding the provisions of section 7 of the Gasworks Clauses Act 1847 as incorporated with the Electric Lighting Act 1882 by Section 12 thereof, and of Section 10 proviso (*b*) of the Schedule to the Electric Lighting (Clauses) Act 1899) subject to the issue of a certificate of the Board of Trade declaring the construction of such lines to be desirable on ground of public utility and

authorising those constructions subject to terms and conditions as are hereinafter provided. Any undertakers requiring to obtain such certificate shall make application therefor to the Board of Trade. Such application shall set forth the purposes of the lines, the advantages of the [illegible] by the exercise of [illegible] there are no other routes and shall be accompanied by a map showing the route or alternative routes proposed to be followed, the easements required for access thereto, the lands and other properties concerned, a schedule of such lands and their owners and a certificate that copies of the map and notices of application have been served upon all such owners. Copies of any agreements which may have been made with any of the owners concerned for the construction of any part of such lines or of any consents given by such owners may be submitted with the application or at any time thereafter until the Board of Trade shall have decided to grant or withhold the certificate.

Upon the receipt of any such application the Board of Trade shall notify the owners concerned, other than those last above mentioned, and invite them to forward to the Board of Trade in writing within one calendar month, any observations which they may wish to offer upon the construction of the lines or the routes proposed so far as their own properties are concerned. The Board of Trade if it sees fit may thereafter hold a local enquiry or may decide to issue or withhold the certificate without such enquiry. The certificate issued shall be accompanied by a plan showing the route or routes approved by the Board of Trade with or without limits of deviation, but such routes or limits of deviation shall be confined to the properties scheduled by the Undertakers in their application. The Undertakers shall within six months of the receipt of the certificate serve upon all the owners concerned, notices of their intention to construct such lines showing the proposed course thereof and of the easements for access thereto and at the same time serve notices to treat for the determination of the compensation to be paid where that has not been previously agreed upon.

The Board of Trade shall make regulations prescribing the scale of the maps, the forms of notice and observations, and the information to be submitted with applications and notices.

When the Board of Trade has decided to withhold the certificate, the undertakers shall not for twelve months or for such period as may be determined by the Board of Trade repeat their application and then only subject to such regulations as the Board of Trade may make.

The exercise of the powers conferred by this certificate issued by the Board of Trade shall be subject to the following provisions:—(1) In the event of failing agreement between the undertakers and any owner of any lands etc. as to the matters set out in the provisions of this section the question shall be heard and determined by a single arbitrator to be appointed by the Board of Trade and so far as possible all questions arising in respect of the line or lines authorized by any certificate of the Board of Trade shall be heard and determined by the same arbitrator acting continuously.

(1) Payment by the undertakers to the owners of the property by way of easement or annual rent [illegible] of such sums as may be agreed upon or awarded as compensation for the reduction in value of the lands by reason of the easements for the construction maintenance and repair of the line and access thereto.

Mr. Chamen

(2) Payment by the undertakers to the owners of such compensation as may be agreed upon or awarded for damage done in the course of construction maintenance repair and alteration of such lines at any time arising.

(3) In arranging whether any wayleaves shall be granted in perpetuity or for any term of years due regard shall be had to the liability of the undertakers to continuously maintain any supply of electricity once given by them.

(4) Alteration from time to time of the route followed by any line on across over or under any lands upon such terms and conditions as may be agreed upon or awarded but so that the alteration shall not cause any interruption to the supply of electricity.

(5) In making any award it shall not be competent for the arbitrator to decide against the express wishes of any landowner or occupier that any electric line shall be run overhead across any ornamental park garden or pleasure ground so as to spoil the amenity thereof.

(6) The Board of Trade may at any time revoke any certificates granted by them under this section upon such terms and conditions as they may determine having due regard to the liability of the undertakers to continuously maintain the supply given by them.

It is not proposed under the Bill to proceed in any other way than through the present existing authority to whom all such matters are referred by the Electric Lighting Acts, namely the Board of Trade, but if any other authority should be set up by Parliament for dealing with this question of wayleaves and/or any other questions at present dealt with by the Board of Trade, the transfer of this matter, along with any other such matters, to any other body, would of course be provided for in the Act appointing such new body. The procedure with regard to wayleaves in other countries has been considered, but it has been deemed advisable to proceed with the drafting of this clause on lines which fit in with the least possible trouble or alteration with the existing conditions in the United Kingdom. The Committee hope that the provisions of this clause give such power to undertakers and to the Board of Trade as it is reasonable to expect that Parliament will give, while at the same time safeguarding the interests of property owners, especially in instances where it might, from a purely utilitarian point of view, be desirable to run overhead lines across ornamental parks, gardens or pleasure grounds, in such a way as to disfigure and spoil the beauty of any such lands. Experience seems to show that the bare fact of the existence of such powers as those set out in this draft clause would suffice in nine cases out of ten, if not, indeed, in ninety-nine cases out of a hundred, to cause the property owner to make reasonable agreements without the actual powers contained in the clause having to be called into operation at all. [illegible] possible for one landlord possessing only a small amount of land to [illegible] upon a scheme for the construction of any electric line not only overhead but also underground, amen.

because he will not allow it to cross his property, or, if he is willing to allow it to cross, the conditions under which he is willing to do so render the scheme impracticable.

There is another point altogether, which has been referred to by the author, namely, that of the alleged right of veto by a local authority against the construction of any lines whatever overhead, even on private property. This alleged right of veto I do not think was ever intended by Parliament. It is not contained in Section 14 of the Electric Lighting Act 1882 and it is really only brought into Section 10 (*b*) of the Schedule to the Electric Lighting (Clauses) Act 1899 indirectly, and I cannot believe for a moment that the Committee of whichever House of Parliament first passed this wording intended that it should give to a local authority the power to prevent overhead lines being constructed on private property, where the public safety and convenience is in no way concerned. Section 1 of the Schedule to the Electric Lighting (Clauses) Act 1899 states clearly that the provisions of the Schedule are to be read and construed subject in all respects to the provisions of the Electric Lighting Acts, which means the Electric Lighting Acts 1882 and 1888, and it is quite unreasonable to suppose that it was the deliberate intention of any Parliamentary Committee to place any further restrictions upon the erection of overhead wires than those contained in Section 14 of the Electric Lighting Act 1882, so far as the consent of local authorities is concerned. The wording of Section 10 (*b*) of the Schedule to the Electric Lighting (Clauses) Act 1899 is of course unfortunate, and if taken literally, as lawyers in these days seem to insist upon taking things, it may be held to give these very wide powers of veto to local authorities, but if the question were taken before any judge who would take a broad, intelligent, and common-sense view of the whole situation, I cannot think he would decide that this clause gives power to local authorities to prevent the erection of overhead lines across moorland or agricultural land or other tracts of country. As, however, the Board of Trade have maintained that Section 10 (*b*) of the Schedule to the Clauses Act 1899 does give an absolute veto to local authorities, without appeal in any shape or form, the Joint Committee have added the following section to the draft Bill :—

> "12. Notwithstanding the provisions of Section 14 of the Electric Lighting Act 1882 and of Section 10 proviso (*b*) of the schedule to the Electric Lighting (Clauses) Act 1899, the consent of the Local Authority shall not be required for the placing of any electric line above ground, excepting along, over, or across any street, and such consent for the placing of any electric line along, over or across any street shall not be unreasonably withheld. Any question whether such consent is unreasonably withheld shall be decided by the Board of Trade.
>
> This section shall only apply to the works of authorized undertakers carried out by them, remaining their sole property and in regular use by them."

The effect of this is to take away all possibility of any claim by the local authority to have any power of veto over the construction of overhead lines on private property, and at the same time it provides that the consent of the local authority shall not be unreasonably withheld to the erection of any electric line above ground, along, over, or across any street, and provides a right of appeal to the Board of Trade, to decide whether any refusal to give such consent by any local authority is unreasonably withheld or not. It must always be remembered that there is no necessity for the local authority to set themselves up as guardians of the public safety, because the Board of Trade are already charged with that duty, which they carry out very scrupulously and effectively. If any local authority should know of any overhead electric lines being erected in such a way as to endanger the public, all they have to do is to draw the attention of the Board of Trade to the matter, and the Board of Trade will very effectively and efficiently do the rest. Many people may ask why these powers of which we complain should not be given to the local authorities as representatives of the public, who, they may say, can surely be relied upon to use them with all fairness and moderation. But the experience of many of us has proved only too clearly that these powers may be and are very grossly misused. For instance, a local authority owning a gas undertaking may and sometimes does make use of these powers to hamper the development of electric light, or even electricity supply generally for power purposes, within its district, being under the impression, apparently, that by so doing it is best serving its own ratepayers' interests by preventing competition with its gas undertaking. Then, again, any councillor having a grudge against an electric power company or other electricity supply undertaker, may so influence the council of which he is a member, as to cause that council to refuse to give the necessary consent. It is therefore quite wrong that these powers of veto, without appeal, should be placed in the hands of any local authorities. No one asks or wants free powers to electricity undertakers to run overhead mains along or across streets without reasonable and proper safeguards in the interests of the public as represented by the local authorities, or across private property without safeguarding the interests of the property owners. But I think that these two clauses in the draft Bill give the necessary relief to electricity supply undertakers, whilst at the same time amply safeguarding the public and the property owners.

Mr. Chamen.

Mr. Grant.

Mr. J. E. GRANT (*communicated*): The paper is a courageous attempt to focus attention upon what is after all only one aspect of the whole difficulty. Taking a broad view there is no difference in principle between a wayleave for a telephone line, power line, telegraph posts, conduits, railways, roads, etc.; and after consideration it will be seen that land for buildings of any kind comes into the same category, a house just as much as a telegraph post. Two weights in the scales of justice are necessary. One weight to provide compensation to the users of the land for any disturbance of improvement, and fair compensation for loss of amenity; the other weight in the scale concerns rating. In the present state of legislation, anyone holding land is penalized by the rates for using it, and escapes by holding it out of use. Our rating system acts like a wet blanket upon industry; nothing could be more unjust. Land is not a product of industry and yet is essential for the purposes of industry. Land without industry would be worth nothing and its value is an induced one, due to the presence of population and consequent industry. If a railway, road, gas, water or power supply line, or any improvement is run [illegible] well known and can be measured as easily as the induced potential in a conductor. Rates as at present placed only upon land that is used, and not upon unused land, produce a monopoly in land and unfairly penalize the user. Taxa[illegible] share of the rewards of civilization. The present system of rating inverts this, and thus industry bears more than its fair share of burdens. The remedy is to rate only the land value and relieve the improvements. Then a man who unfairly held up valuable land would be asked to pay rates upon its value to the community. Let us now see what would happen in the case of wayleaves. The user of the land would have the value of his displaced improvements assessed by an independent impartial assessor and also be offered fair compensation for loss of amenity, if any. If he refused the just offer he would be asked to pay a sum equivalent to the annual land-value rate agreed to be paid by the power company, railway, or water-supply company as the case may be. Under such a system no land-holder would be unduly selfish, it would not pay. It is only fair that if for personal reasons he wishes to deprive the community of some benefit, he should give fair compensation. The recommendations of the Land Enquiry Committee only treat the difficulty in piecemeal fashion and are calculated further to increase bureaucratic officialdom, all of which leads to further taxation burdens. A universal remedy is required which will give justice to every industry, and that remedy lies in more equitable rating.

Mr. W. T. Kerr (*communicated*): The difficulties of obtaining wayleaves and easements as described in the paper relate more especially to heavy power lines, but they are more intensified in the case of light overhead lines suitable for giving a supply in agricultural districts. It seems to be of little use for the Board of Trade to suggest the linking up of stations and the conservation of coal and petrol supplies until the above obstructions are removed. Take, for instance, the case of the farmer. On farms in this district (Herefordshire) at least one oil, gas, or steam engine is used per farm. Each of these engines necessitates a certain amount of carting of fuel; this means the use of horses, each of which is said to require 1½ acres [illegible] necessary. By substituting electric power this item could be saved. But these engines cannot be replaced by electric motors so long as the cost of an extension line is in some cases doubled or even trebled by heavy legal costs and prohibitive rents. In many cases these costs would be disallowed as a capital charge and very few engineers [illegible] that the main should be put [illegible] was mentioned about overhead lines. A [illegible] that many of those who object to overhead [illegible] may often be seen crossing [illegible] I fail to see why a power line should be forbidden when there is no perceptible difference to the ordinary public. At the present time it is of the greatest importance that every reasonable facility should be given for the extension of electricity supply mains. In my opinion the inducement thereby offered to agriculture is such that many times the acreage would in future be arable land. I have recently heard farmers say that the best type of ploughing gear is steam-driven. By substituting a motor, however, on the winding drum, the cost of this equipment would be reduced by several hundred pounds; and by doing away with the small engines the cost of insurance would also be reduced. Extensions in agricultural districts are, however, out of the question owing to the difficulty in obtaining wayleaves. Also the methods of levying rates on these lines need revision; they should on certain conditions come under the same category as agricultural land, covered by Section 211, Sub-section 1B of the Public Health Act 1875. Legislation on the lines of a combination of the 1916 Telegraph (Construction) Act and the "Recommendations" of the Land Empire Committee would enable supply undertakings to meet the demands now being made upon them for a supply of cheap power for agricultural and rural industries, and at the same time enable the larger generating stations to be linked up, thereby effecting a general economy of the greatest national importance.

Sir W. Slingo (*communicated*): I am in sympathy with the objects aimed at in the paper and note with satisfaction that the Post Office view that extra-high-pressure lines should not be erected along public roads is held by the author. There are a few essential points of difference between the circumstances attending telegraph lines and power lines. One of these points is that the business is more concentrated in the latter case than in the former, that is to say, the expenditure incurred upon, and the revenue derived from, a mile of power line are both greater than in the case of a corresponding length of telegraph line. It follows that the cost of the wayleave is relatively less important in the case of the power line. So far as consents are concerned, local authorities have no power of approval or disapproval of Post Office telegraph or telephone schemes, i.e. their powers are restricted to giving or withholding consent for the construction or erection of plant in specified positions in streets or roads, and the Postmaster-General has the right of appeal to the Law Courts against the refusal of consent or the attachment of objectionable conditions. It has been laid down in the Courts that any condition attached to a consent given by a local authority must be restricted to such as can reasonably be attached in its capacity of road authority. There can be no doubt that a time limit should be imposed, but I fear some difficulty will be experienced in securing a limit of only one month. In the case of telegraph and telephone work the Engineer-in-Chief of the Post Office is himself a co-ordinating authority from the standpoint that he issues technical instructions to his engineers and in the normal course of administration endeavours to secure that those instructions are observed uniformly throughout the United Kingdom. In the case of power work, the standards are prescribed by the Board of Trade, and if the existing power of the local authority to veto or modify a scheme is to be qualified by a right of appeal to the Board of Trade, the latter would become not only the

v. go.

source of Regulations for securing the safety of the public, etc., but also the referee in cases of dispute. The experience of the Post Office has indicated very clearly that there is a marked difference between the standard of workmanship in the case of the large electric light and power undertakers on the one hand and the very small undertakers on the other, and there is much to be said for the principle of referring all differences to tribunals which could only be claimed to be impartial, but before which the Board of Trade could if necessary be represented. Long experience has indicated that the procedure prescribed for telegraph lines works on the whole satisfactorily, and I should be very sorry to see any Government department (which by the way would act through the intermediary of barristers) acting as arbitrators, substituted for the Law Courts. I very much doubt whether there would be the same uniformity in decisions or whether the costs would not be considerably enhanced. In the matter of wayleaves on private property, the Post Office has had to contend with precisely similar difficulties to those mentioned by the author, and it was mainly in consequence of the increase in those difficulties since the acquisition of the National Telephone Company's system (at the end of 1911) that the late Postmaster-General (Mr. J. A. Pease) decided to seek further powers, which has since been conferred by the Telegraph (Construction) Act, 1916. The main effect of this Act is to secure for the Post Office in respect of differences regarding the use of private property a right of appeal to the Law Courts similar to that enjoyed since 1878 in the case of differences with road authorities. The remarks already made with regard to references to the Board of Trade in connection with the approval of electric light and power schemes apply with equal force to the question of settlement of differences with private owners, i.e. there seems to be no good reason why the machinery provided by the Telegraph Acts should not be utilized to facilitate the operations of electric light and power undertakers. I may add that the 1916 Act has already proved to be of very great service. The author draws attention to the fact that many of the routes for power circuits lie across agricultural land; but those circuits are often in the vicinity of towns and villages or lead to factories, works, or collieries, and there is always the liability that such land may be required for building purposes, and, whether the lines be overhead or underground, some provision for possible diversion is essential.

bourn.

Mr. B. WELBOURN (*communicated*): The magnitude of the evil is generally admitted, and no good purpose is to be served at the moment by quoting additional hard cases. It therefore seems to me better to concentrate on the discussion of the proposals which the author makes or alternative ones. In the discussion Mr. Williams suggested that the matter is one of considerable importance to the manufacturers of electrical machinery, etc., as well as to the supply authorities. I agree. I think that any manufacturer who is capable of taking long views and has faith in the future developments of the electricity supply business will agree that any reasonable procedure which tends to increase the number of consumers must also increase the market for his products. I hold, therefore, that electrical manufacturers are likely to derive much benefit from the simplification of the present procedure in regard to consents and wayleaves. What can be done to remedy existing conditions? On page 337 the author makes a suggestion that the Board of Trade should be authorized to issue a public utility certificate for a transmission line and that the receipt of such a certificate would be a powerful implement to have in hand when negotiating for wayleaves. I suggest that it would be better to take the attitude that all transmission lines are required for public utility purposes and that the onus of disproof should be put on the owner of the land proposed to be crossed. It seems to me that this will be simpler from our point of view than to attempt to define the term "public utility." Attempts at a definition will lead to all sorts of difficulties. For instance, no reasonable person would be likely to object to the term "public utility" as applied to a line for giving a supply to, say, a colliery, but if the line were required for a supply to, say, a cinema, the matter might be open to discussion. On page 331 the author omits to make any proposal for a time limit for settlement of disputes by the Board of Trade. In regard to consents, I would ask him to make his proposal more definite and to bring it into line with the three months which he states on page 336 for wayleaves. When listening to the London discussion I was impressed by the proposal made by Mr. Stubbs to the effect that the immediate difficulties might be met by the passing at once of a short Bill which would confer on the electricity supply industry similar rights to those which were conferred on the Postmaster-General by the Telegraph Construction Act of 1916. This would certainly be a stepping stone towards the more drastic legislation which may come as the result of the work of the various Board of Trade Committees.

Mr. Welbourn.

Mr. C. VERNIER (*in reply*): I wish to thank the President, Mr. Wordingham, and other speakers for their appreciative remarks on the paper. I am very glad to find that there has been no opposition, but a unanimous expression of opinion in favour of the measures aimed at in the paper although, as was only to be expected, there have been differences of views on questions of detail and procedure. The paper was intended to create an opportunity for expressing such views, in order that the Council, and others who will have to deal with this question, might have the benefit of the opinion of members qualified by experience to speak on this subject. The President has mentioned that I was invited to contribute the paper by a Committee of the Institution. I would express regret that it has taken so long to comply with their wishes, for it was shortly before the War that I was first approached in the matter, and I must put the blame for the delay on circumstances arising out of the War which prevented me from finding sufficient time to undertake its active preparation until quite recently. I am glad to think, however, that nothing has been lost by the delay, as there could scarcely have been a more opportune time for a discussion of this subject when the question is becoming a really live one; if the discussion had taken place in the earlier part of the War when other more serious matters required pressing attention, the matter might by this time have lapsed once more into obscurity. Now that the Board of Trade have (since the paper was written) appointed a Committee to inquire into the general question of affording an ample supply of electrical energy to all who require it, this question of wayleaves cannot be ignored

Mr. Vernier.

[illegible] which the Committee have been [illegible]

[illegible] Mr. [illegible] because in writing it I have been at some pains to hold the balance as evenly as possible between the several interests, [illegible] r—not an easy matter—neither taking the view [illegible] considers any interference with private property to be a form of sacrilege. The latter type is not very likely to be found within the ranks of electrical engineers, but the former is not unknown and a word of warning must be uttered, which is that any extreme views will only defeat the object we have in view.

I regret that contributors to the discussion have appeared to confine their remarks almost entirely to the question of wayleaves for overhead mains and have generally ignored the question of wayleaves for underground cables. I attach quite as much importance to the latter, and I am of the opinion that as regards wayleaves for underground cables in open land and in private roads we have an unanswerable claim. I know no valid reasons why undertakings of unquestioned public utility should not have the same or similar powers extended to them as are conferred [illegible] for the laying of sewers and water pipes on private land. Mr. Williams in quoting my reference to parks and commons, I fear, had only in mind wayleaves for overhead mains, but I do seriously put forward the suggestion that compulsory powers should be granted for carrying mains everywhere irrespective of whether the land is park land or moorland, and my view finds support in the terms of Section 1 of the Telegraph (Construction) Act 1916, which makes no reservation as to the kind of land to be utilized, but only as regards the amenities and the value of the land. It should be the duty of the Government Department concerned to decide in case of disagreement whether in the circumstances the amenities of the site render overhead construction unreasonable, and undertakers themselves would in the majority of cases exercise some common sense of the fitness of things in these matters. Only recently I have had occasion to lay an [illegible] able shortening of the route, [illegible] are to be excluded from compulsory powers, costly and unnecessary deviations may [illegible]

Mr. Woodhouse has very properly suggested that I should make some reference to the report of the Joint [illegible] Mr. Woodhouse, doubtless speaking [illegible] for increased facilities for way- [illegible]

Question 1.—"Whether notwithstanding the provisions [illegible] powers should be given in any cases for acquiring land compulsorily for generating stations; and if so, under what conditions as respects liability for nuisance, notices to surrounding owners and otherwise."

> [illegible] The proved public advantages of electrical energy in the generation of light and power warrant in their opinion the granting of compulsory powers for acquiring sites for generating stations and lands or easements for pipes and mains therefrom and other works.
>
> [illegible] subject to confirmation by Parliament. Such provision would facilitate a continuance of the existing practice, according to which more or less uniform conditions under which undertakers are to work are provisionally settled by the Board of Trade. Procedure by private Bill should be reserved as at present for exceptional cases."

This recommendation has been acted upon in numerous Provisional Orders and Acts since it was made, and has finally been incorporated in electrical legislation in Section 1 of the Electric Lighting Act 1909, but it must be clearly understood that compulsory powers can only be exercised in connection with land which is specified in an Act or Order.

Question 3.—"Whether, in case of a generating station, however acquired, not being situate within the area of supply, power should be given for the breaking up of streets between the generating station and the boundary of the area of supply";

> [illegible] powers being given for the erection of a generating station outside the area of supply they think that powers may properly be given for laying the mains in streets leading from the generating station to the boundaries of the area of supply. In such case the local authority liable to maintain these streets should have the same option of themselves breaking up and reinstating the streets at the undertakers' expense as is now given in the Provisional Orders to local authorities within the area of supply, and should be empowered accordingly.
>
> [illegible] it may be advisable to maintain the veto of local authorities as to the erection of overhead wires given by Section 14 of the Act of 1882, in respect of other electric wires, it is not advisable that in the case of overhead wires for traction purposes the local authority, other than the London County Council and county boroughs, should have an absolute veto. While due weight should be given by the Board of Trade to the representations of local [illegible] *locus standi* to such local authorities."

[illegible] with reference to the breaking up of streets outside the area [illegible] nier.

reference—as showing what we have to meet in the matter of consents for overhead wires. The Board of Trade, doubtless with this report before them, drafted Section 10 (*b*) of the Electric Lighting (Clauses) Act 1899 even more stringently, or perhaps I should say less ambiguously* than the similar clauses contained in Section 14 of the Electric Lighting Act 1882, but nevertheless, in the Power Bills of 1900, Parliament allowed an appeal to the Board of Trade in the case of the unreasonable withholding of a consent by a rural district council. Much has obviously happened in the electrical development of this country during the 19 years which have elapsed since this Committee sat, to call for a revision of this matter, and, as I have stated in the paper, a right of appeal is necessary in all cases of the unreasonable withholding of a consent by a local authority.

Mr. Woodhouse does not agree with the exclusion of county boroughs, and this is also my own view, but I think it very likely that their inclusion would be strenuously resisted. There is a difference between a county borough and a municipal borough,† and it is only the former to which I refer in the paper. It is quite true, as Mr. Woodhouse points out, that parts of some county boroughs are as open as any rural districts and will probably not be fully built upon for generations. It is important to bear in mind on this question that the right of appeal to the Board of Trade by no means implies that the appeal will be granted. Representations by a local authority to the Board would have full consideration and thus no real hardship could be placed upon the local authority. As further emphasizing the necessity for this right of appeal, I should like to mention that the whole of the Northumberland coal-field is covered by two county boroughs, one municipal borough, 12 urban districts and small portions on the outskirts of two rural districts, and any one or more of the above authorities, excepting the rural districts, can absolutely veto the erection of overhead lines to give a supply to that particular coal-field, and all or any of them may impose restrictions and cause vexatious delays as described in the paper.

Security of tenure, as Mr. Woodhouse points out, is somewhat precarious, but I can assure him that other undertakers would only be too pleased if they could always ensure even 21 years' agreements.

Mr. Starr's model conditions are much more modest in that he appears to be satisfied, unless I misunderstand him, to remove his mains at 6 months' notice. This question of security of tenure is undoubtedly a most important one, but overhead construction on any extensive scale has been too short a time in operation to form any judgment of the attitude landowners are likely to adopt when agreements expire, whether they will not in some cases call for removal of the lines or for an increase in the rents. In either case what can the unfortunate undertaker do? He is helpless if the landowner chooses to be unreasonable. Let us imagine under the present arrangement a line several miles long which has been in use for a number of years supplying important consumers, and which passes over several estates. If a landowner on one of these estates on the route refuses to renew an agreement, or only agrees to renew it on more extravagant terms than before, and if his estate is a large one, the whole line may have to be diverted to clear his land and the continuity of supply endangered, or alternatively his terms, whatever they may be, must be accepted. The opportunties thereby offered for blackmail by an unscrupulous owner are practically unlimited. Under a law for expropriation tenure should be in perpetuity unless the landowner can show good cause for the removal or diversion of the main, such as the necessary development of his land, which makes this essential. My recommendations (*d*) on page 337 are intended to prevent unreasonable interference with the property of undertakers, but at the same time a landowner ought not to be prevented from enjoying freedom in the use and development of his land in any reasonable manner, and therefore in all but unreasonable cases the cost of carrying out the diversion should fall upon the undertakers.

Mr. Vernier.

A further question which has not been dealt with in the paper is that of compulsory powers to cut and trim trees to enable cross-country overhead lines to be erected satisfactorily. Such powers are contained in the Swiss and French Laws on expropriation and must not be overlooked in any proposed legislation on this subject.

I must congratulate Mr. Starr on the absence of serious difficulty with wayleaves or consents in his district. It would almost seem as if the further one travels south, the more difficulties increase. The organization of a special department to deal with all negotiations for wayleaves is one that has been in existence for many years in the company with which I am connected, and is, in my opinion, essential if difficulties resulting from the absence of a proper organization are to be avoided. Such difficulties are often experienced where the handling of negotiations is left in the hands of local or district engineers responsible for the execution of the work, who are invariably occupied with a great many other duties and who not infrequently look upon the whole business as a tiresome nuisance to be got over as best they can. The individual best qualified to undertake these negotiations is not met with every day and should be plentifully endowed with tact and unlimited patience, and he must, in addition, possess a certain personality and knowledge and experience of agricultural matters which enables him to meet land agents and farmers on common ground. For some reasons it is preferable that he should not be an engineer.

County councils, as pointed out by Mr. Starr, are the local authority in most cases in Scotland. It is well to bear in mind, however, that for the purposes of the Electric Lighting Acts, a county council outside of Scotland and the County of London is not a local authority, but merely a highway authority. This is important, as some county councils have not hesitated to claim as a local authority the right to veto overhead wires, a claim to which they have usually no legal right. In one or two of the Power Acts, viz. the Gloucestershire, and the North Metropolitan Power Act 1907, the county councils have

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* This is ambiguous because it can be read either as prohibiting the erection of overhead wires above ground on roads only or above ground generally including roads, in each case without the consent of the local authority.

† County boroughs are boroughs which at the passing of the Local Government Act 1888 had a population of not less than 50,000 or were counties in themselves (Section 31).

The local authority is in some cases defined in the Schedule to the Electric Lighting Act 1882 as being the urban sanitary authority now known as an urban district (Local Government Act 1894, Section 21). A municipal borough is also an urban district.

[illegible]

Like Mr. Starr's company, other undertakers have also found it convenient to agree upon standard terms with the [illegible] in the paper in regard to exorbitant rents, I can find no word in my vocabulary fittingly to describe the measure of the exaction by railway companies in cases where statutory powers cannot be exercised. With some knowledge of the treatment railway companies met with at the hands of landowners when purchasing their land, one can but feel that this is looked upon as a legitimate opportunity for recoupment at the expense of other undertakers.

I consider that the method of assessing a rental on the basis of the number of units passing over the line or main should be strenuously resisted. This is virtually giving a share in the business of the undertaker to grantors of wayleaves, a share to which they have not the shadow of a right.

The interests of private owners certainly demand that the grantor of a wayleave should be fully compensated for the use of his land, but the absurdity of the claim will be better understood when I point out that a 20,000-volt cable capable of carrying between 8,000 and 10,000 kw. will occupy no more space and cause the owner no more inconvenience and disturbance than a low-tension cable capable of carrying less than 500 kw., and the same remark applies to overhead mains according to the pressure adopted. Such an arrangement as the one under discussion, quite apart from necessitating heavy and unnecessary expenditure in providing metering [illegible]—particularly at the higher voltages as to which we have reached no finality—imposes a perpetual fixed charge, and what amounts practically to a tax on each unit carried by the main, irrespective of the value of those units or of any economies which the undertaker may be enabled to [illegible] whatever might be said for it in the case of a private undertaker, in the case of statutory undertakers it is in my opinion, absolutely contrary to the public interest.

Mr. Starr has also referred to the question of wayleaves for laying mains in private roads, i.e. roads dedicated to public use but repairable by the owner. Statutory powers to break up private streets and roads of this character are [illegible] streets, if not scheduled, can be broken up [illegible] consent in every case. The procedure laid down requires [illegible] in respect thereof shall be settled by arbitration.* In view of what I have already stated in connection with wayleaves for underground cables in open land and private roads it will, I think, be clear that I am thoroughly in agreement with Mr. Starr's views on this question.

Mr Vernier.

While on this subject, I should like to call attention to valuable clauses inserted in a Bill promoted by the Newcastle and Gateshead Gas Company last year, viz. [illegible]. These clauses are chiefly designed to enable the laying of mains in new estates where streets are laid out but not yet taken over by the local authority, and are as follows :—

> 23. [illegible]—The Company may on the application of the owner or occupier of any premises within the limits of supply abutting on or being erected in any streets laid out but not dedicated to public use supply those premises with gas and for that purpose the Gasworks Clauses Act 1847 shall apply as if Section 7 of that Act were excepted from incorporation in this Act or the recited Acts.
>
> 24. *As to private streets.*—(1) The local authority of the district within which any street not repairable by the inhabitants at large is situate shall be deemed in addition to any other persons to be persons having the control or management of such street for the purposes of the provisions of the Gasworks Clauses Act 1847 with respect to the breaking up of streets for the purpose of laying pipes.
>
> (2) For the purpose of this section the expression "street" includes a street laid out but not dedicated to the public use.

The right to lay underground mains over railway bridges is not very satisfactory even where undertakers have been granted statutory powers. Some railway companies have claimed a rent for a wayleave wherever the cable or trough touches the bridge structure, on the ground that while it is clear that the undertakers have statutory powers to lay their mains in the sub-soil of a highway repairable by the local authority and carried over a railway by means of a bridge,† if the cable touches the bridge structure the railway company is providing means of support. It is quite clear in any event that the bridge structure must not be interfered with,‡ and this is frequently an impossibility because of the way railway companies are allowed to construct their road bridges without leaving sufficient depth of sub-soil to allow of the laying of mains and pipes over them.

As regards the provision of means of support, I believe that this claim is one which cannot be legally substantiated.§

The President, Colonel Ogilvie, and Mr. Wigham have emphasized the more favourable position which non-statutory undertakers occupy as compared with statutory undertakers in the matter of erecting overhead wires on private property and across roads by consents of the rnier.

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* [illegible]

† [illegible]

‡ [illegible]

§ [illegible]

owners of the adjoining land. This seems at first sight unjust and unreasonable, and although the reasons are quite well known to many, they may be of interest to others. The essential difference between non-statutory and statutory undertakers is that the former are practically independent of all State regulation and control, whilst the latter, for reasons quite familiar to economists, are not. They come, therefore, under no restrictions whatever in the ordinary way from the Electric Lighting Acts, and are only subject to the general law in so far as it affects their operations. The legal position is this: Where the works of a non-statutory undertaker are erected on private land, the owner of the land can consent to the placing of poles and wires on his land, and no one can prevent him from exercising or delegating the right to use his private property as he thinks fit, provided always that he thereby commits no nuisance to his neighbours. Across public roads the position appears a little more complicated, but is not so in fact. The sub-soil of a highway dedicated to public use remains the property of the landowners on each side of the road who own up to the centre of the road. The highway authority, usually the local authority (but sometimes a county council), and other statutory bodies such as electricity, gas and water undertakers, have only the right to the use of so much of the sub-soil as is necessary to enable them properly to discharge the duties imposed upon them by the State, such as the maintenance of a road surface, the laying of cables, pipes, sewers, drains, manholes, etc., and no more.

In addition, a landowner not only owns the sub-soil and all it contains to a depth which is only limited by his coming up against his neighbour from the antipodes somewhere about the centre of this planet, but also, in theory at least, owns the air up to the limitless depths of space. He cannot, however, interfere with, or break up, the road surface without the consent of the local authority, nor, on the other hand, can the local authority claim any more of the air space above the highway than is necessary to enable such highway to be used as a highway.

From this explanation, it is quite clear how it is that a landowner is in a position to enable a non-statutory undertaker to exercise rights over his land, and over public roads without the consent of the local authority in the manner described on page 330 of the paper. It should, however, be mentioned that apart from the adoption of by-laws under Part II of the Public Health Amendment Act 1890, and in London under the London Overhead Wires Act 1891,* by some very few local authorities, which by-laws regulate and do not prevent the erection of overhead wires, some corporations, e.g. Manchester, Southport, Darwen, Blackburn, etc., have obtained statutory powers to prevent the erection of overhead wires along or across streets without the consent of the corporation. Generally speaking, however, outside of towns and villages there will be found to be no restriction whatever to prevent the crossing of public roads with overhead wires by non-statutory undertakers. At the same time there may be some risk of interference at a later date if the local authority secures powers or if an urban authority, or with the consent of the Local Government Board a rural authority, adopts by-laws which the overhead wires already erected contravene; but a non-statutory undertaker who usually only wants to run a few lines and not a general distributing system* can well afford to take this slight risk. The position of non-statutory undertakers is more favourable to them in another direction in that they are not compelled in many cases to erect or lay their overhead lines and mains in accordance with Board of Trade Regulations. It is true that under Section 4 of the Electric Lighting Act 1888 the Board of Trade may serve a notice upon such undertakers, requiring that their lines "shall only continue to be used in accordance with such conditions and regulations for the protection of the public safety and of the lines and works of the Postmaster-General as the Board of Trade may by such notice prescribe," yet as the Board of Trade are usually totally ignorant of the existence of such lines, there being nothing to compel a non-statutory undertaker to communicate with the Board of Trade or to serve a notice upon them, the usual application of this section of the Act follows only after an accident to the public or whenever the Postmaster-General requires some special protection for his works. This cannot by any means be considered a satisfactory state of things, and although it might be thought to be a matter of little or no concern to statutory undertakers, it effects them in this way, that accidents to the public arising from bad design or indifferent workmanship usually result in new and more stringent regulations being applied to statutory undertakers, and also because such accidents which are avoidable reflect generally upon the whole industry and may vitally affect its development.

Mr. Vernier.

Sir William Slingo, I am pleased to note, refers to the marked difference in the standard of workmanship between large electric light and power undertakers on the one hand, and the very small undertakers on the other, and although he does not say so, I have little doubt that the smaller undertakers he had in mind would in the majority of cases be non-statutory undertakers.

Sir William Slingo, Colonel Ogilvie, and Mr. Stubbs have each given very interesting information as to the experience of the Post Office in the matter of wayleaves for overhead telegraph and telephone lines. As Colonel Ogilvie points out, the chief requirements of the Post Office are for overhead lines along roads and to a much lesser extent on private land, whereas the requirements of power supply undertakers are just the converse, in that their overhead lines require to be placed mainly on private land, and outside of towns or villages—which I have specially excluded from the scope of the paper—are but infrequently required along public roads. My reference to the satisfactory powers available to electricity supply undertakers on public roads must therefore be limited in its application to underground mains. Mr. Stubbs foreshadows that the Post Office engineer will watch that the Postmaster-General's rights shall be duly conserved in connection with any legislation proposed on behalf of the electric power authorities. With the experience of the Electric Lighting Acts before me, I have no doubt whatever in the matter. If landowners literally own the earth including the air around it, up to the heavens above and the depths beneath, it can truly be

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* These by-laws do not apply to statutory undertakers, who come under the Board of Trade Regulations.

* In some cases overhead distributing systems have been erected by non-statutory undertakers in this manner. Finchley Electric Light Co., Ltd., *v.* Finchley Urban District Council (1903).

Mr. Vernier.

[illegible] service. I have no fault to find with this arrangement so [illegible] tion and with a due sense of the responsibility which they [illegible] being be secondary to that of the Post Office, but may yet rival that great undertaking.

Turning to the more debatable points in the discussion, viz. that of the best procedure to be aimed at in the exercise of compulsory powers for expropriation, the views of the majority of the speakers are in favour of the powers recently conferred upon the Postmaster-General under the Telegraph (Construction) Act 1916 being extended to electric light and power undertakers. I share Mr. Wigham's doubts as to whether Parliament would consider for a moment the granting to electric power engineers of the right to say they intend to run a power line compulsorily on any particular route, although, like him, I should welcome such powers, always provided that they were accompanied by some guarantees that they would not be abused, as all powers which may be abused, if not used rightly usually prove in the long run to be a hindrance rather than a help. We must not forget that the position [illegible] of executive power, is very different from that of electricity supply [illegible] the President of the Board of Trade, who himself holds the executive power. Parliament might, however, quite reasonably confer upon the Board of Trade the authority to make [illegible] modifications) to the construction of approved electric mains and lines of public utility. In my opinion, the weak point of this Act, especially after hearing Colonel Ogilvie's remarks on the experience of the Post Office with stipendiary magistrates and county court judges, lies in the fact that these constitute precisely the tribunal to whose judgment the question must be referred in the first instance, and further that these same tribunals have also before them the determination of the question of whether [illegible] or is not in the public interest, a matter upon [illegible] by Colonel Ogilvie. It is true there is a right of [illegible] judicial body, viz. the Railway Commissioners, which might ensure uniformity of practice; but if frequent [illegible] be found to be too cumbersome and costly for [illegible] the machinery pro- [illegible]

[illegible] recommendations of the Land Enquiry Committee, which places the determination of the rent in the first place in the hands of the district valuer, i.e. the district valuer for the purpose of the duties on land values, a State official with a knowledge of local values and unbiased in favour of either the undertaker or the landowner, together with a right of appeal to a judicial body comprising expert members. Their simplicity and cheapness, in my opinion, stamp these recommendations as superior to any of the methods already in force or suggested. It is further important to note that the decision as to the exercise of compulsory powers here rests with the Government Department concerned, in our case the Board of Trade. I think that the Institution and other bodies who will be invited to give evidence before the Departmental Committee of the Board of Trade should consider this matter very carefully with a view, if thought fit, of strongly endorsing the Land Enquiry Committee's recommendations and supporting any legislation which may be under consideration for giving effect to these recommendations. Having carefully considered the trend of the discussion, I would make the following suggestion as possibly not beyond the possibility of attainment, i.e. that the recommendations of the Land Enquiry Committee be acted upon so far as present machinery exists, and that the Government Department concerned, viz. the Board of Trade, should be authorized to make an order for a compulsory wayleave, that the rent be fixed in the first place by the district valuer, and that a right of appeal be allowed to the Railway Commissioners.

We must always bear in mind that the individual sums involved in the case of wayleave rents will usually be small, often under £10, and very seldom exceeding £20 per annum in total to any one owner in any given case on a particular route. Taken by themselves, these rents may appear unimportant; but on account of the number of different owners concerned, and separate routes and therefore cases in the aggregate, they assume quite different proportions. It is therefore most essential that any machinery provided must be so readily accessible and inexpensive that supply undertakers will not hesitate to use it, not, I may remark, entirely in their own interest, but in the much more important interest of the national welfare. This is the first consideration; the second is promptitude in obtaining a decision from all concerned. It is not unlikely that my suggestion that a time limit should be imposed upon a Government department will somewhat shock official circles, but the time for dilatoriness in matters of importance to the industries of the nation surely came to an end with the outbreak of war on the 4th August, 1914. Let it be observed in connection with my suggested time limit of one month upon replies from landowners and occupiers, that already a reply must be given by them within three weeks under Section 15 of the Electric Lighting (Clauses) Act in the case of private roads unless they are prepared to agree to the proposed works.

As to the [illegible] on the question of fixing the compensation rent, I think it is a foregone conclusion that unless some other method is strongly pressed upon the Board of Trade the Department would, following precedents, decide either to apply Section 1 (2) of the Electric Lighting Act 1900 which incorporates the provisions of the Lands Clauses Acts for the compulsory purchase of land (including easements), or to refer the matter to arbitration under Section 28 of the Electric Lighting Act 1882. There are already no less than 20 different matters of dispute in the Electric Lighting Acts which may be referred to arbitration under this last clause.

Several speakers have referred to the proposed Supply of Electricity Bill, and to the clause which has been incorporated in that draft Bill dealing with the question of wayleaves. I may say that I am in ignorance of the contents of this Bill,[*] and that while the information was privately accessible to me, I have purposely refrained from seeking it, preferring to bring out my own views for the purpose of creating a free discussion, which views may or may not coincide with those in the proposed Bill. The views expressed in the paper therefore must not in any way be taken as an expression of the views of either an Institution Committee or of the Municipal and Power Companies' Associations. All private Bill legislation being debarred at the present time, the only means of getting anything through Parliament until the War is over, and for some time afterwards, is by means of a Government measure; and the recently appointed Departmental Committee provides the obvious channel to effect this. Mr. Williams would like to see in any recommendations which are made some reference to the Electricity Board which he advocated in his paper to the Institution last year.[†] There is no difficulty that I can see in Parliament delegating some of the duties now performed by the Board of Trade to such a Board if and when it is established, but I scarcely think that this Board would be a proper body to undertake the duties intended to be placed in the hands of the Judicial Land Commissioners advocated by the Land Enquiry Committee, duties which have to do solely with land and not with electricity supply.

Mr. Kerr has referred to the question of the rating of electric mains. I have often been impressed by the number of people who are in complete ignorance of the fact that electricity supply undertakers are rated upon their mains, and who moreover express surprise when they are told that undertakers have to pay rates for their mains even when they are placed on private or agricultural land. I quite agree with Mr. Kerr that the present basis of assessment for rating of electric mains requires revision. There is no sufficient reason to my mind if a railway company is only assessed upon one-fourth of the annual value of its lines and sidings and any land providing means of support thereto (but excluding stations and buildings), why the mains of an electricity supply undertaking should be assessed on any higher basis. The reason for the partial exemptions mentioned in the clause quoted by Mr. Kerr appears to be that sanitary arrangements are made chiefly for the benefit of houses and buildings, while the properties enumerated do not receive the same benefit.[‡] I think this is a matter which the electrical industry should certainly bring to the attention of the Local Government Board with a view to its extension to electric mains.

I have to thank Mr. Welbourn for calling attention to an oversight in omitting to refer on page 331 to the necessity for a time limit in the matter of an appeal to the Board of Trade against the unreasonable withholding of a consent by a local authority. I think it follows clearly from my previous remarks that I consider this quite as essential in the case of a consent as in that of a wayleave. In the case described under paragraph 3, out of the total delay of 9 months, 5 months represent the time taken up by the Board of Trade in considering and deciding in the appeal. Mr. Welbourn has also touched upon what I expected might prove to be a most contentious point in the discussion, viz. that of "public utility." The "public utility" of a main or supply in the sense in which it is used in the paper must not be confused with its "public convenience," and, where property rights have to be interfered with, the "public necessity" must be clear and unquestionable. In a general sense, all electric supply mains of a public supply undertaking are of "public utility," but they are clearly not all of equal "public necessity." I have already stated my views (page 360) on the question of supply undertakers having the right to set in train machinery for the exercise of compulsory powers without a reference to the Board of Trade, and as for the suggestion that the onus of disproof of the public utility of a main should be placed on the owner of the land, that in my opinion would be viewing the matter in a wrong perspective. The rights of private property must be paramount until it can be shown that they are contrary to the public interest. Thus we see that the Telegraph (Construction) Act 1916 places upon the Postmaster-General the onus of proof "that such refusal is contrary to the public interest." Mr. Vernier.

Mr. Grant has dealt with the subject of wayleaves from a totally different point of view from other speakers, viz. that of the rating of site values and the unrating of improvements."[*] As I understand him he is not in favour of direct compulsory measures but prefers the more subtle application of the principle of self-interest. I question very much whether in this case the method would prove very effective. As I have pointed out, the rents usually involved in any given case are comparatively small, although the capital sums in the case of a "hold up" are not, and I cannot conceive a landowner with a rent roll in many cases running into four, five, or six figures, being seriously influenced into granting a wayleave by any considerations such as these.

I thank Messrs. Sayers and Kingsbury for their contributions to the bibliography of the subject, and I trust if other members can fill the lacunæ in the paper in respect of the laws on expropriation in other countries, that they will kindly forward them to the Secretary for addition to the records of the Institution and for the benefit of all interested.

Mr. Kingsbury also referred to the report of a Parliamentary Committee issued in 1885, and opines that if it has taken 30 years for the Post Office to obtain the powers recommended by this Committee, it will take a considerable time for similar powers to be carried through Parliament by electricity undertakers. I regret that I cannot share his views, as this would ignore all the pioneer work in educating Parliament and the public, which was undertaken by the Post Office and others during those years.

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[*] Since completing this reply I have received Mr. Chamen's communication which gives full details of this clause. I shall deal with his communication in the June Number (No. 267) of the *Journal*.

[†] *Journal I.E.E.*, 1916, vol. 54, p. 581.

[‡] "Encyclopædia Britannica," vol. 9, p. 439 (India paper edition).

[*] These questions are discussed very fully in the Land Enquiry Committee's Report, vol. 2, p. 554.

[illegible] This was succeeded by a further measure in 1908, and lastly by the more recent one of last year. [illegible] show a progressive relaxation of restrictions, and I think unmistakably point to a slow but steadily growing appreciation of the relative importance of public versus private interests by those concerned. In conclusion, I do not [illegible] that of being an [illegible] but I am not unmindful of the fact that for close upon three years public opinion has been moulded in the severest school that ever fashioned a generation of people, and that possibly one of the greatest changes which will emerge from the stupendous conflict which is shaking civilization to its very foundations is a truer and wider recognition of the ethical principles that the welfare of the community is more important than the profits of individuals, that private liberties and privileges should give place to the public weal, and that the ownership of wealth confers duties as well as rights.

Mr. Vernier

It is in this deeper and more hopeful sense, and under the stimulus of a newly awakened national spirit that I perceive public opinion is becoming rapidly more enlightened and instructed, and although the old prejudices die hard, I am confident that they must speedily yield, if not earlier then under the moral and economic pressure of post-War conditions.

[illegible]

SOME POINTS IN CONNECTION WITH ENGINEERING SPECIFICATIONS.

By J. SHEPHERD, Member.

(*Paper received 10 December, 1916; read before the* YORKSHIRE LOCAL SECTION 21 *February, before the* MANCHESTER LOCAL SECTION 27 *February, and before the* SCOTTISH LOCAL SECTION 3 *April, 1917.*)

The importance of specifications to the purchaser, the contractor, and the engineer, can hardly be overestimated, as they form the basis of contracts and should include a concise description of the purchaser's requirements so as to enable orders to be placed in a business-like way for the plant or material required.

Specifications, whether long or short, should contain all salient facts necessary for the contractor to carry out his work, and should include a lucid description of the conditions under which the contract is to be completed.

Specifications for work of some magnitude usually consist of three distinct parts, namely, general conditions, detailed technical requirements, and a bill of quantities.

General conditions.—The general conditions, which are of the nature of standing orders, are usually of a legal character. They are of great weight and importance, and are usually drafted by solicitors or town clerks. In many cases they have grown to imposing documents, and unfortunately have sometimes formed a weapon which has been used to the detriment of the industry generally, since they have resulted in orders being sent abroad where the foreign contractor, owing to his distance from this country, has escaped the results of several of the conditions.

The British Electrical and Allied Manufacturers' Association have been engaged for the last few years in framing an independent set of conditions. These favour the manufacturer's rather the purchaser's interests, and up to the present have not received general acceptance. The Institution have drawn up and issued an independent set of conditions, and as the committee entrusted with the work comprised representatives of both manufacturers and engineers, the result has been a set of conditions which should be generally equitable to both parties.

Whatever general conditions are adopted, I am strongly of the opinion that all matters in dispute should be referred to independent arbitration, provided that the progress of the work is not prejudiced thereby; that is to say, the two sides should agree as to what points are in dispute, and these can then be the subject of independent arbitration after the work is completed.

Detailed technical requirements.—This part of the specification is entirely the engineer's province, and in it he has clearly to define his requirements. Before he can do so he must make up his mind as to what he really does want, and having done so he should lay down his requirements in the simplest language.

There should be no necessity in modern specifications for the threadbare phrase: "Notwithstanding any errors or omissions the work omitted shall be included as though specifically mentioned."

Bill of quantities.—Wherever possible the work should be scheduled, and a complete list of quantities closely estimated and arranged for pricing up should be given. In this bill of quantities should be included any provisional sums for extra work or for any special apparatus which it may be desired to purchase.

Having very briefly outlined the skeleton of a specification, a few examples may now be given of various specifications drafted during the last dozen years for various classes of engineering work required for a large public body who was the purchaser. In considering these specifications the attitude of the purchaser must not be forgotten. That attitude might perhaps be defined thus:—

> "The market includes a large number of willing and eager suppliers anxious for our contracts at reasonable prices; the engineer shall therefore draft a clear and concise specification free from all looseness of thought or description, or errors of any character. When the tenders are received to such a specification, we can, without misgiving of any kind, accept the lowest tender, no matter from whom it may be, and in order that we may know that the prices tendered are reasonable, the engineer shall submit, with the tenders, and before they are opened, his estimate of the cost of the work."

The specifications described below have all been drafted to suit such a general condition of affairs as far as it is possible to do so, and those members who do not agree with the drafting of the specifications must bear in mind the conditions under which they were drawn up.

One essential difference between a specification for machinery of standard design and a specification for, say, civil engineering or architectural work, should at once be observed. No engineer with whom the author is acquainted is so bold as to issue working drawings of, say, a turbogenerator, high-speed engine, or watertube boilers which he may desire to purchase. On the other hand, nearly all civil engineering and architectural work is the design, and is carried out to the detailed drawing of the civil engineer or architect. But even in this branch of the profession the old order is changing with newer methods of construction, such as structural steel work, reinforced concrete, etc., which requires certain of the designs to be left to the specialists who handle this type of construction, and there is but little doubt that in the future the change will become more pronounced [illegible] These are :—

(1) [illegible]

(2) To define the conditions and results to be obtained, leaving the contractor to meet the requirements with his standard products if they are suitable.

If the engineer specifies the conditions and the results required, and leaves the manufacturer to offer his standard designs, the results will generally be satisfactory if the engineer is allowed to select as his contractors a firm of [illegible]nce and of ripe experience. Unfortunately, [illegible] premises were that the lowest tender should be [illegible]

Again the manufacturer has not always extensive experi- [illegible] rectifying the weak features of a design, which use alone will discover. Also it is not uncommon for some manufacturers to perceive with difficulty any defects in their products. The defects, when investigated, not infrequently [illegible] to drawing-office instructions not reaching the shops in [illegible]

The following are the salient features of a number of recent specifications.

COAL.

In a large generating station having a good load factor, [illegible] coal at normal prices, the generating costs per unit may be taken to be as follows :—

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Repairs to plant and buildings	[illegible]
Total	[illegible]

Coal and ashes thus represent 78 per cent of the total, [illegible] is required for the supply of coal and the removal of [illegible] With the present high prices of coal the pro- [illegible]

[illegible] described below [illegible]

Roughly the specification may be said to contain and set out:—

Quantity required, viz. 165,000 tons per annum ;
Minimum quality to be accepted, viz.
  Calorific value must not be less than 11,000 B.Th.U.
  Moisture must not exceed 14 % for washed nuts or [illegible] % for unwashed nuts.
  Small coal must not exceed 30 %.
  Ash must not exceed 15 %.

Delivery by steamer, and the berthing conditions are also set out.

Methods of sampling are given in detail, but in later specifications the final sampling was done by a motor-driven crusher and sampler.

Methods of testing are then specified, namely—

(*a*) For small coal, through a sieve with a mesh $\frac{3}{8}$ in. square.
(*b*) Calorific value by Mahler bomb calorimeter.
(*c*) Moisture after drying at a temperature of from 104° to [illegible]
(*d*) Ash determined by ignition at a low red heat.

When tendering, the contractors are requested to state both the price and the values offered of the following particulars :—

(*a*) Calorific value in British thermal units.
(*b*) Moisture in percentage by weight.
(*c*) Small coal
(*d*) Ash

These values must not be inferior to the minimum values allowed as already described.

The specification provided for the adjustment of the price paid for any particular cargo in accordance with the values actually obtained for that cargo, the adjustment being made as set out below.

"Should the quality of the coal in any cargo, as ascertained by samples tested, be found different, as regards calorific value, moisture, small, or ash from the values offered in the schedule, the prices or sums payable as aforesaid shall be varied in the manner following, viz.—

"(*a*) If the calorific value be greater than the number of British thermal units per pound offered in the Schedule, the price per ton shall be increased in the same percentage ratio as the increase in the calorific value.

"(*b*) If the calorific value be less than the number of British thermal units per pound offered in the Schedule, the price per ton shall be decreased in the same percentage [illegible] always that the Council shall have the right to reject the whole cargo if the calorific value be less than 11,000 British thermal units per pound.

"(*c*) If the moisture be less by weight than the figure offered in the Schedule, the weight of the coal to be paid for shall be increased beyond the quantity actually weighed out by a percentage equal to the percentage decrease of moisture.

"(*d*) If the moisture exceed by weight the figure offered in the Schedule, the weight of the coal to be paid for shall be decreased below the quantity actually weighed out by a percentage equal to the percentage increase of moisture. Provided always that the Council shall have the right to reject the whole cargo if the moisture exceed 14 per cent by weight for washed nuts or 9 per cent by weight for unwashed nuts.

"(*e*) If the proportion of small coal in either singles or doubles be less by weight than the figure offered in the Schedule when determined in the manner set out in Clause No. 10 of this Specification, the weight of the coal to be paid for shall be increased beyond the quantity actually weighed out by a percentage equal to one-quarter of the percentage decrease of small coal.

"(*f*) If the proportion of small coal in either singles or doubles exceeds by weight the figure offered in the Schedule, when determined in the manner set out in Clause 10 of this Specification, the weight of the coal to be paid for shall be decreased below the quantity actually weighed out by a percentage equal to one-quarter of the percentage increase of small coal. Provided always that the Council shall have the right to reject the whole cargo, if the proportion of small coal exceeds 30 per cent by weight.

"(*g*) If the percentage of ash when determined in the manner set out in Clause No. 10 of this Specification be less than the figure offered in the Schedule, the net rate per ton of coal shall be increased by one penny for every one per cent reduction in ash.

"(*h*) If the percentage of ash when determined in the manner set out in Clause No. 10 of this Specification be more than the figure offered in the Schedule, the net rate per ton of coal shall be reduced by one penny for every 1 per cent increase in ash. Provided always that the Council shall have the right to reject the whole cargo if the proportion of ash exceeds 15 per cent."

The adjustment may appear somewhat cumbrous, but in practice is not found to be so, and an actual copy of an invoice worked out in detail is set out below.

Cargo of Scotch Nuts.

Weighed on delivery 1,447 tons 10 cwt.

	Values determined by analysis	Values offered in tender	Difference
Small	14·70 %	20 %	+ 5·3
Moisture	13·45 %	9 %	− 4·45
Cal. Val.,	13,070 B.Th.U.	12,500	+ 579 = 4·56 %
Ash	8·53 %	10 %	+ 1·47 %

Basis price for quality tendered 15s. 10d. per ton.

	T.	cwt.	qr.	£	s.	d.
Coal as weighed	1,447	10	0			
Deduct for 4·45 % moisture ...	64	8	1			
	1,383	1	3			
Add for small ¼ (5·3) = 1·325 %	19	3	2			
	1,402	5	1 at 15s. 10d. =	1,110	2	6
Add for calorific value 4·56 %				50	12	5
Add for ash 1·47d. per ton				8	17	4
				£1,169	12	3

Note: Price at net (tendered) rate of 15s. 10d., i.e. 1,447 tons 10 cwt. at 15s. 10d. would have been £1,145 18 9

Bonus on the cargo £23 13 6

The reasons for the adjustments of prices are fairly obvious.

The price varies directly as the calorific value, and inversely as the percentage of moisture. As regards small coal, for each 4 per cent increase, the rate is diminished 1 per cent.

The ash is indirectly allowed for by diminished calorific value, but a further penalty of one penny per ton for each one per cent increase over the standard figure is deducted to cover the cost of conveying the ashes away by barges.

As the coal tendered by different contractors may, and usually does, vary in value, the rates per ton offered cannot be directly compared without adjustment to a common basis of "standard coal" which, for the purpose of comparing tenders, was taken at:—

Small 20 %
Calorific value 12,500 B.Th.U.
Moisture 9 %
Ash 10 %

After the comparison had been made and the tenders awarded, all further adjustments for payment were made in a similar manner to the example given.

The volume of business dealt with by specifications of the character described was 100,000 tons in 1906, increasing year by year to 160,000 tons in 1915. This necessitated the removal from the boiler house of from 10,000 tons to 16,000 tons of ashes per annum.

The coal usually purchased under these specifications was Scotch washed nuts, shipped from various ports on the Firth of Forth, and Yorkshire washed nuts, shipped from Goole. The Yorkshire coal has the higher calorific value, but when burnt under watertube boilers it was found to be more destructive of the brickwork seatings.

If the recovery of by-products becomes practicable in a power station, modifications in the specification for coal will no doubt become necessary to suit the nitrogen contents of the fuel.

In passing, it might be remarked that a specification for fuel is somewhat unique, having nothing quite analogous to the ordinary run of civil engineering or architectural practice.

The specifications have enabled purchases to be made in the open market for the past 10 years without giving rise to a single dispute as to the value of the coal determined on delivery and for which the price was adjusted as shown in the example given.

LAYING CABLE CONDUITS.

In a large underground electrical distribution system the cables are either drawn in or laid solid, and both systems have their advantages.

For a large town with expensive surface reinstatement, the solid system is unsuitable; whilst for an urban district the draw-in system is too costly.

The work of laying cable ducts is very similar in character to that of laying gas or water pipes. The method adopted by one of the Government Departments was to pay a fixed rate per lineal yard of work actually carried out, the contractor taking the risk of difficult work and having to stand the loss of work partially completed but abandoned owing to obstructions encountered later.

Such a method of contracting is open to many objections as the work becomes too speculative, the unknown quantities being too great. Either the contractor loses a lot of money or else he provides large amounts for contingencies [illegible]

In work of a similar character which the author has carried out, the specifications for the work, though more elaborate, were found to be fair to both parties in so far as difficult work, if met with, is paid for at tendered rates set out in the bill of quantities, and, if difficult work is not met with, the contingencies provided for are not required.

The general body of the specification contains but little novelty, the chief interest being in the bill of quantities, which is divided into three sections, as follows :—

(A) *Duct-laying* of various numbers of cable ducts laid in every kind of roadway or pathway construction. The rates tendered per yard run, cover excavation to normal depths and widths, removal of useless obstructions, lighting, watching, fencing, etc., carting away surplus material, levelling the bottom of the trench, laying conduits or pipes in cement, concrete, and mortar, filling in the trench, ramming and permanently reinstating the surface, testing each cable-duct line, including the cartage of the ducts from the nearest depôt.

The rates tendered cover work laid both at normal depths and in trenches of normal width. If, when carrying out the duct-laying, deeper trenches or wider excavation be found necessary, adjustment in rates are made, as afterwards described.

(B) *Construction of manholes.*—The manholes for drawing in the cables are spaced about 100 yards apart and are of two types and various sizes to suit the bank of ducts.

The work of constructing the manholes is divided into the following sections :—

- (*a*) Excavation of the ground.
- (*b*) The foundation upon which the box is built.
- (*c*) The brickwork of the box.
- (*d*) The construction of the top or cover of the box.
- (*e*) The permanent reinstatement of the surface, whether road or footway.

If the manholes are of standard size, the rates tendered directly apply. If they are of necessity larger in depth or width, the new prices can be immediately built up from other rates, given in the next section.

[illegible] of all alternative [illegible] may be required, such as excavation for extra depths or for extra widths, extra bricklaying at various depths, rates for concrete laid at various depths, timbering left in trenches, steel or cast-iron piping, paving and surface reinstatement of every kind, etc.

In practice it has been found to be comparatively [illegible] specification of this character and with a [illegible] When, however, [illegible] extraordinary difficulty, [illegible] running sand, or the like, provision is [illegible]

Work to the value of £250,000 has been carried out to specifications of this character with but one dispute where a particular class of work had been incorrectly priced and the estimated quantities of that class of work were largely exceeded.

Substation Switchgear

Having no less than 23 substations containing rotating machinery of from 2,000 kw. to 6,000 kw. capacity, the problem of purchasing switchgear became one of importance.

Two methods were adopted. At the commencement general requirements to be met were stated, leaving the maker to supply his standard apparatus to meet the conditions laid down. Three substations were equipped in this way by two contractors ; one for the high-tension apparatus and the other for the continuous-current feeder-panels. The result was not satisfactory. One contractor supplied his panels of marble, the other insisted on slate ; and the two classes of panels had varying widths and heights. These difficulties, however, were minor matters compared with other troubles met with.

Within six months the low-tension panels had practically to be rebuilt, and within six years the high-tension panels had to be scrapped to suit Home Office Regulations.

For all later substations the second method was adopted, viz. to issue working drawings of all the panels and apparatus and to loan to the contractor parts for interchangeable manufacture.

The method was entirely satisfactory to the purchaser ; competitive tenders on equal footing were obtained and sound and interchangeable switchgear was purchased, requiring a minimum quantity of spare parts.

It became a simple matter to interchange panels from substation to substation as conditions of load required.

All high-tension switchgear was contained in brick cubicles and only two accidents occurred during 10 years' working. In each case the damage was confined to the one cell where the short-circuit occurred.

There are, of course, drawbacks to such a system of purchasing. It is not adapted for purchases on a small scale, and it becomes difficult with standard designs to introduce modifications from time to time, which otherwise in a smaller system would be adopted. On the other hand, the maintenance of such switchgear was particularly good, amounting to practically nothing on the high-tension side, and it was generally confined to renewals of circuit-breaker contacts on the low-tension side.

It became possible to standardize such details as all porcelain insulators, and a sheet of standard porcelain was loaned to each contractor in turn.

Reconstruction of Motor-Generators

After working continuously night and day, several of the earlier motor-generators began to fail from various causes, such as soft cores, broken core teeth, brittle insulation on the armatures and stators, charred insulation on the field windings, etc.

After careful consideration it was decided to reconstruct on the basis of every 10 years [illegible] (about 18 hours per day), and the first year's programme included the reconstruction of 17 motor-generators of 300 kw. and three motor-generators of 500 kw. capacity. An estimate of the cost of the work was furnished and the makers of the plant were approached for prices. As the results were by no means comparable, a specification was drafted, working drawings were got out and tenders invited by advertisement, the prices tendered being:—

(A)	£7,987 10s.
(B)	£8,330
(C)	£14,100
(D)	£20,321
Engineers' estimate	£11,500

The lowest tender was that of a firm practically unknown, but a visit to their shops proving satisfactory, the contract was let to them at the price tendered and the result was in every way satisfactory.

Owing to improved methods of winding with "hairpin" formed coils, a much sounder construction resulted, giving an increase in output of 25 per cent on the original rating, and a renewal of life to certainly another 10/15 years.

The machines were originally constructed in 1902 and 1903 and the frames were then liberally proportioned.

The contractors who carried out the work took on further contracts at substantially the same rates.

GENERAL.

Having described in brief outline a few specifications covering various branches of engineering, the author would by no means dogmatize or even go so far as to say that the only way to buy engineering plant is by detailed specification. It is, however, the only way he knows of by which one can purchase plant on the conditions laid down. A free agent can purchase on different lines if he is free to select his tender, no matter what the price may be; but, even so, a clear specification as to what is offered is necessary both to limit the supplier's responsibility and to define his liability. The basis of all contracts depends upon much besides the wording of a specification, and implies fair and reasonable dealing on the part of both supplier and purchaser, without haggling on the part of the supplier or needless complaints or meddling by the customer's engineer. In conclusion the author would remark that, to specifications such as those described, over £2,500,000 worth of work has been purchased, and of that large sum not more than £1,500 was spent abroad, and that for articles which were not manufactured in this country. In the past a large amount of foreign purchasing has taken place, resulting in the foreign manufacturer frequently escaping rigid inspection, burdensome general conditions, exacting wage rates, and other labour conditions. This condition of affairs is not, however, likely to be repeated during the next 10 years, nor, it is to be hoped, for a much longer period.

YORKSHIRE LOCAL SECTION, 21 FEBRUARY, 1917.

Ir. Selvey.

Mr. W. M. SELVEY: A specification cannot possibly be so complete as to cover every possible detail. Some specifications of large concerns are now very voluminous and very legal documents. I am in favour of such complete specifications being drawn up where their extent is due to the incorporation in them of clauses covering actual experiences, as these clauses are really definitions of the conditions under which the plant has to work. The trouble begins when some partly informed engineer or buyer attempts to adopt in their entirety such specifications for a plant which is to operate under entirely different conditions. I have known cases where the contractor has had to explain to those who have issued the specifications what certain clauses meant, and why they were inserted, and has been able to get the admission of the customer that they did not apply. It is for this and similar reasons that the model conditions of contract of the Institution have been such a help, and although these are not yet perfect, they do form a reasonable basis from which to aspire to greater perfection. As regards specifications in a general sense, as distinguished from those which have been built up by many years of actual experience in a particular concern, I am gradually coming to the view that the safest way for a customer to buy a plant, where it is impossible for him to be acquainted with the details of what he wants, is to base the proposed contract not on the apparatus or plant bought, but on the purpose for which it is required, and practically to omit any detailed particulars or detailed description of the plant. If it is perfectly clear that the contract is for apparatus or plant, particularly and solely to produce a certain result or to do certain work, and the contractor accepts that obligation in a simple way as the basis of the contract, then the buyer's rights at common law are very much greater than any detailed specification can possibly give him. From this point of view a specification is really a limitation of the obligations of the contractor. There is probably a much greater chance of equity on a broad issue as to whether the plant purchased really fulfils the desired purpose than when it is a question of interpretation of certain clauses of the detailed specification. However carefully this specification is drawn, there is always some clause which may give rise under the arbitration clause to a dispute.

Mr. Selvey.

Mr. Woodhous

Mr. W. B. WOODHOUSE: I was very much taken with the author's statement that the conditions drawn up by the manufacturers favoured the manufacturer's rather than the purchaser's interests. I am afraid that some of the conditions are obviously unjust, just as in the past some of the purchaser's conditions have been obviously unjust, but I think that the present is not a time to discuss conditions of contract. The ideal condition of contract from the purchaser's point of view is that the manufacturers shall give him a certain article to his engineer's complete approval. The tendency lately has been for manufacturers to say: "We will sell our standard article. We expect to get a certain performance from it. If we do not it cannot be helped." Those are the two extremes. Between the two one hopes that some reasonable compromise will be made. With regard to coal specifications, I am not a believer in calorific value alone as a basis of price; I believe that the author's specification would be equally valu-

[illegible] calorific value. The require- [illegible] and as to [illegible] and small coal [illegible] but in practice I think one finds that calorific value does not fully indicate the value of a particular coal to the user, which depends not only on the fuel but on working conditions, and on the [illegible]. One may use a coal with a low calorific value [illegible] with a high calorific value. What is important to the user is the net value of the material he is buying. He is buying a certain amount of carbon, and a certain amount of volatile matter which is of value ; he is buying in addition water and ash, which are of no value, so that the net material is the combustible minus the water and the ash. Now the net value is something rather different, because if one considers the case of a very dirty coal, which, for example, has 50 per cent of ash, one can take it that in the ordinary mechanical stoker such coal is practically unburnable. Therefore if I were drawing up a specification in which the price paid depended on these various factors, I would make it depend on the amount of combustible less the amount of water, less, for example, twice the amount of ash, which would compensate to some extent for the fact that, as the amount of ash increases, the value of the coal decreases still more rapidly. But the nature of coal is a very complex subject and we want to know a great deal more about it before we buy on an absolute specification of a chemical or heat-value nature. The physical specification setting out the proportion of small stuff, the proportion of combustible, and the proportion of ash, is, I think, of the utmost value. I consider that the author's concluding remarks deserve most careful study. The bases of the conditions of contracts and specifications must be fair and just. If they are in the hands of an engineer who will take that broad view, I think both the purchaser and the manufacturer can rest content.

Mr. R. H. CAMPION : I want to take up a point in connection with the penalty clauses in the General Conditions. I recently had a contract with a very well-known firm of engineers, the work was specified to be finished by a certain date, and I added that if the contractor was not able to agree to this date he was to mention his date. They all filled in my date, but several of them told me it was quite impossible to do the work in the time, so I put the question to the contractor whose tender was successful, and he said "Oh yes, he would have it done." The result was that it was 6 months late. The question of penalty then arose, and the firm told me that they had never paid a penalty in their life. It seems to me that we are wasting time in going to all this trouble with General Conditions and agreeing to them, if we are not going to enforce penalties. I do not agree that the Institution's General Conditions are equitable to all. There is time to revise them, and one hopes they will be revised later on. I agree that [illegible] against the manufacturer, and that now the manufacturer is swinging it too much the other way. I have noticed that manufacturers are very reluctant to give details of [illegible]

I was pleased to notice that the author says that provided the specification is properly drawn up there is no harm in accepting the lowest tender. With the choice of the two methods of specifying, I think there is no doubt that the second condition mentioned by the author is by far the best, as it does not attempt to tell the manufacturer how to manufacture, but only specifies the requirements and requires that they should be met. I should like to know how many coal merchants were able to tender to that specification, because I was under the impression that it generally went to one man, and I thought in that case he would probably allow a good sum to cover all these very stringent conditions. In connection with another station on the same river which consumed more coal, I understand that their coal specification contained as many lines as there were pages in the other specification, and the results were quite satisfactory. I quite agree with the author that the Yorkshire coal does destroy the brickwork very much. With regard to the laying of cables and conduits, that is the easiest and the simplest specification which one has to draw up and work to in order to get work done ; it seems to be that there one gets on to a better basis with the contractor and the work proceeds more smoothly. With regard to switchgear, one wonders if the original circuit breakers that were installed would have been able to stand the work after a little time, as I understand that the very severe conditions which were experienced at the beginning with regard to the starting up of this system were enough to upset any switchgear. With reference to the reconstruction of the motor-generators, one would like to know if the conditions would have been allowed in standard machines at the present time. The author was undoubtedly able to get very good results by rewinding. This is the only place in the specification where I conceive the engineer's estimate is of much use. In most of the other cases I think it is almost a waste of time for the engineer. He cannot say what a turbo-generator will cost to manufacture ; he can only note the prices at which other people's tenders are being accepted, and a few things of that kind. I think the most interesting statement in the paper is in the last paragraph, where it is stated that the best way to buy engineering plant is by specification, but that seems to be quite contrary to the American practice at the present day. A friend of mine who recently visited America to buy plant had the greatest difficulty to get the Americans to tender to any specification. They would not even tender to their own. The principal thing they seem to want to know is what the plant is going to cost when they buy it, and as long as they can get 100 per cent out of it they seem quite content.

Mr. Campion.

Mr. G. A. HART : Some of the points in connection with engineering specifications which the author has introduced have both a direct bearing and a significance on general engineering practice, including that in which I am more particularly interested. Public authorities invariably prepare and submit their own sets of conditions governing engineering contracts into which they enter, and it is a matter of the highest consequence to the engineer, his client, and the contractor that the general conditions of contract should be carefully regulated to be in harmony with the true nature of the particular class or branch of engineering contracted for. Had this point been more

Mr. Hart.

Hart. carefully observed in the past, I think we should have had a more confidential spirit pervading the relations of both buyer, or seller, or client, and contractor, with a corresponding diminution of those imposing documents which the author has referred to; nor should we have witnessed the drafting of rival sets of conditions of contract framed for the protection of manufacturers' interests as opposed to the interests of the purchaser. I should have been glad if the author had somewhat elaborated the reference which he has made in his remarks to bills of quantities, more especially to the relation of bills of quantities to the conditions of contract. In civil engineering contracts for public works I have had experience of two methods governing the relations of bills of quantities to the conditions of contract, viz. (1) contracts in which the bills of quantities are not embodied in the contract, and (2) contracts in which the bills of quantities are embodied in the contract and form part of the contract documents, forming the basis of contract. It would be interesting to know which classification it is customary to adopt in the electrical engineering profession. The first-named method throws the entire responsibility upon the contractor to frame a tender upon a specification of description of work assisted by a set of contract drawings, and necessitates the contractor accepting responsibility for checking or perhaps even taking out a set of quantities to enable him to give what is called a lump-sum tender. By the alternative method where quantities are embodied in the contract, either the engineer may stipulate that he will be responsible for the accuracy of the quantities—in which case the tender sent in would be a lump-sum tender governed by and subject to deductions and additions—or alternatively, the bill of quantities may be stipulated to form a schedule of prices intended merely as a guide for the purpose of obtaining competitive tenders based upon dimensions or quantities which are believed to be reasonably accurate, but not sufficiently accurate for the actual work to be carried out by the contractor. My experience leads me to believe that a lump-sum tender in general engineering practice for works of any degree of intricacy or magnitude is rarely found to be satisfactory to the contracting parties. Engineers rarely have the time necessary to prepare the careful detail drawings and elaborate specifications that would be required, and even if this were the case it is obviously irksome and frequently very unfair to expect each contractor to devote considerable time on the part of a skilled and technical staff to prepare the necessary quantities to enable him to give a lump-sum tender. My own experience is certainly in favour of embodying the bills of quantities in the general conditions of contract as forming part of the contract, and of restricting their significance to the limited degree of forming the basis of a schedule of prices and methods of measurement upon which the actual work, when constructed in situ, shall be measured by the engineer.

Lang. Mr. W. LANG: I wish the author had indicated what is the real use and intention of a specification, because my idea of a specification is that it is intended to be in two parts, first to avoid litigation by drawing up such general conditions as would be fair to both sides, and in the second part to provide the contracting party, the seller, with a guide to what he is called upon to do. I doubt very much if specifications to-day are really achieving the one or the other object. Most people will, I think, agree with me that instead of avoiding litigation the general terms almost lead into it, since the author states that whenever a loophole is found through which a contractor might squeeze, the town clerk or other governing body adds a further clause to avoid that difficulty. This would seem to indicate that the general conditions applying to contracts will increase to such a size that they will prevent the general contractor from making an offer. In fact I think experience to-day is that where a specification does not appeal to a man's sense of justice or he feels he is independent of conforming to the requirements, he returns the specification and asks to be excused. I do not think that is at all a desirable business outlook for us. In fact I think that if the engineering profession were to take as their example Lloyd's, who will draw up on half a sheet of paper a specification covering the risk of fire, etc., for one's house or any other risk, to almost any amount, it might be possible to avoid these lengthy engineering specifications. If the author will refer to the last page of the paper where he states that four offers were made for certain motor-generators, he will admit that those offers came from firms whom he would consider good enough to carry out the work. If the lowest price had been received from a firm in whom he could not place confidence, I think the offer of that firm would not be entertained. So that when we say in our specification, or in the problem that we are considering, that if the quantities, materials, and design are so set out then we are justified in accepting the lowest tender, I think we must admit that we should only issue that specification to those firms whom we think are on a par with one another for their quality of work. At any rate if an unknown firm without any record of any substantial work to their credit were to submit the lowest tender I should be very surprised if they got the order. Mr. Lang.

Mr. W. H. WRAITH: From the point of view of contractors, the specification is a half-way house between two engineers, the engineer on behalf of the purchaser and the engineer on behalf of the contractor; and the more open and straightforward the specification, the more harmoniously is the work carried out. Mr. Wraith.

Mr. A. R. CHAYTOR: One or two speakers have referred to the varying natures of the so-called essential conditions as set out in various specifications, and I should like to endorse that view. A case which came before my notice only a short time ago will show the contrast very well. The specifications were for practically identical work, the one contained 31 foolscap sheets of general conditions, 12 of special conditions, 16 of detailed technical requirements, and 2 of bill of quantities, the other was composed of 9 sheets for general conditions, 2 of special conditions, 6 of detailed technical requirements, and 5 of bill of quantities. The figure mentioned by the author as being deducted from the actual costs for all labour in connection with the excavation and reinstatement of cable-conduit trenches is interesting, but I cannot conceive it to be of general utility for even rough estimates for this class of work. For one-way and two-way routes the figure is decidedly high, and I assume that it has been derived from the cost of work on a much bigger scale than this. Furthermore, my experience points to the fact that for conduits laid in the horizontal plane the costs follow a straight-line law (after the first conduit), but for laying them row on top of row the proportionately cheaper jobs, Mr. Chaytor.

[illegible] [illegible] are cross-section, i.e. when the total number is either [illegible]

[illegible] on which finally to decide is an actual boiler test of bulk samples obtained from two or three of the most likely tenders. After a class of coal has been chosen in this manner make regular calorific tests to ensure that the [illegible]ers keep to the original value of the coal chosen. The class of coal and the constituents which cannot be found except by a chemical analysis are as important as the calorific value where coal is used for firing a boiler. For any but an engineer of a large power station with a correspondingly large staff, to prepare an estimate for plant is, I think, out of the question. An estimate can only be based on what one knows of the current market selling price. To attempt to work out a manufacturing estimate is not possible for moderate-sized engineering [illegible]

[illegible] important matters in dispute to independent arbitration should receive general acceptance. Where special apparatus is required and is included in a specification under provisional sums, it seems only fair to allow a contractor a commission of from 5 per cent to 10 per cent for passing the same through his books. The author's specification for coal is very interesting and he is fortunate in getting [illegible]rs to supply fuel under a scientific system. I [illegible] calorific value, ash content, and moisture, but I could not get a single one to agree to such conditions. Let us hope that in time they will see that they have nothing to lose and perhaps much to gain in agreeing to such a specification as that proposed. I shall be glad if the author will say whether the British thermal units mentioned are for coal "as received" or "dry," as that point is not quite clear. Evidently water-borne coal contains much more moisture than coal conveyed in railway trucks. I am surprised to see a percentage of 14 for washed nuts; my experience is that unwashed fuel invariably contains a greater percentage of moisture than washed fuel does. In Sheffield, the average percentage of moisture in washed nuts [illegible] in 1916 was 3·24 per cent, and for mixed [illegible] [illegible] of coal are delivered, a system of testing [illegible] author recommends is satisfactory, but [illegible] culties would arise where train loads of vary- [illegible] [illegible]tisfying coal contractors who are invited to [illegible] [illegible] lition contain over 60 per cent [illegible]

reasonable dealings between suppliers and purchasers are commendable.

Mr. J. Shepherd [illegible] I must explain that the paper was prepared under War conditions, which did not allow leisure for writing more than a general paper. A few representative specifications were selected and the salient points of each explained.

With Mr. Selvey's remarks I am generally in agreement; if the purchaser's conditions of working require a particular type of plant or machinery such plant should be specified in detail. If his requirements are normal in character, then a more open specification will meet the case. Again, the condition of inviting tenders by advertisement, and of having generally to accept the lowest one, can only be met satisfactorily by specifications and drawings prepared with great care and set out in some detail.

I am surprised to hear that Mr. Woodhouse does not believe in purchasing coal on a heat basis under the conditions enumerated in the paper. Experience shows that purchase to specification of the character indicated was the only feasible method under the conditions stated. Had these conditions been different, the methods of purchase could also be different, as I endeavoured to point out. Mr. Woodhouse agrees, however, with the inclusion of the percentage of small coal and the percentage of ash, but in my opinion he omits the most important fact of all, namely, the calorific value. So far as I am aware, coal is the only mineral sold without full consideration of its chemical constituents, and the engineer buys coal for its calorific value alone.

Mr. Campion discusses the question of penalty clauses. It is one of the most difficult matters to extract penalties from contractors for late delivery, and perhaps this is as it should be, and such penalties can only be extracted when delay in delivery has caused a corresponding or greater loss to the purchaser. I am surprised to hear that Mr. Campion does not agree with the Institution's Model General Conditions, though he does not indicate which particular point he objects to. Turbine blading is hardly within the purview of the paper, but it must be remembered that the industry of turbine-building is by no means established in all its details, and whilst in a state of development manufacturers are reluctant to give away what they may consider to be exclusive information. With respect to coal specifications, tenders were received against such specifications from practically every coal merchant in London whose facilities enabled him to tender for either the whole or a considerable portion of the contract. The conditions in the other station which he mentions as purchasing coal on a shorter specification are different, so that the methods of purchasing may also be different. The conditions of the specification for coal-purchasing were not stringent: they simply provide that should better coal be furnished than quoted, a better price for such coal will be paid. If the coal furnished be not so good as that tendered, a lower price would be paid, and the contractor himself must fix the values of the coal inserted in his tender. A wider method of tendering could scarcely be imagined. With respect to switchgear, Mr. Campion is scarcely correct in stating that the severe conditions of working occurred only at the start. These conditions become more severe the larger the substation feeding the lines and the heavier the service of cars upon them. As an example, at

Mr. Selvey.

Mr. Shepherd.

Mr. Shepherd.

the commencement half-mile sections of line usually required 300 to 500 amperes, and of late years the load on a number of these sections has grown to 1,000–2,000 amperes per half-mile. In reply to the questions respecting the increase in capacity of motor-generators on re-winding, the framework of modern machines is not generally so liberally designed as that of machines constructed 10 or 12 years ago. Under present abnormal conditions I agree with Mr. Campion that it is difficult to frame reliable estimates and it is not easy to buy, though I have not found conditions so difficult as he suggests.

In reply to Mr. Hart, I consider that the bill of quantities in a specification is really the whole root of the tender and forms the essence of the contract. It is generally possible to take out quantities with sufficient exactness to be accurate within 10 per cent.

In reply to Mr. Lang, I quite agree that the idea of all specifications should be fairness and conciseness to avoid by all possible means uncertainties and litigation resulting therefrom. That the specifications described merit this description is borne out by the fact that in some hundreds of contracts only one case of litigation arose, and that was settled in an amicable manner without prejudice to the progress of the work. Apart from the written matter of specifications there should always be fairness in the interpretation of the clauses, otherwise contracting and purchasing would be difficult or impossible, certainly under present conditions where work is so plentiful. The four tenders named by Mr. Lang were received in reply to public advertisement. The lowest was from a firm quite unknown to me and I do not think they had any record to show of work of a similar character and size, yet this firm obtained the order and carried out the work satisfactorily. Indeed, open tendering and clear specifications is one of the best ways of widening the market and allowing comparatively unknown firms an opportunity of showing their merit.

In reply to Mr. Chaytor, it is found from analysis of many tenders that the cost of duct-laying follows nearly a straight line law, and why the record of such prices should not be of general utility for estimating purposes, I am at a loss to understand. Personally I know of no surer way of estimating than to base estimates upon actual costs.

I note that Mr. Nevill does not agree with buying coal on a calorific basis. I can only say that 10 years' experience of buying on this basis has in every way been satisfactory. With respect to engineers' estimates, my own work has largely consisted in the preparation of estimates of every kind and description, and the smallness of the staff required for such estimating would no doubt surprise him.

In reply to Mr. Yerbury, there was no difficulty in obtaining quotations from coal merchants in London on the basis of the specifications described, though I am aware that when dealing with collieries direct it is generally impossible to purchase in this manner. I know of no fairer method of purchasing, as the bonus system enters largely into every variety of modern bargaining. The basis of purchasing in this way is to ask the contractor to fix his price and the quality, and to pay him a bonus if he exceeds this quality, and to make a reduction if the quality of the coal delivered be not up to the tendered values. The calorific value was determined on dry fuel. As all the coal purchased was water-borne, I am unable to make any comparison between water-borne and rail-borne coal. I can say, however, that Yorkshire coal is generally drier than Scotch, as the following figures show, taken from two years' deliveries when Scotch washed nuts and Yorkshire washed nuts were being delivered concurrently :—

Yorkshire nuts, moisture	10·23 % max. to	3·25 min.
Scotch nuts „	16·9 „	„ 9·6 „
Yorkshire nuts, moisture	7·83 % max. to	4·0 min.
Scotch nuts „	15·5 „	„ 9·5 „

I quite appreciate the difficulty of sampling and testing when many deliveries are received daily by rail.

Manchester Local Section, 27 February, 1917.

Mr. Watson

Mr. S. J. WATSON : The information which the author gives us in regard to fuel is of very great importance because, as he rightly points out, fuel to-day, so far as our power stations are concerned, represents the largest item in the account. If, by paying special attention to the details, economies can be effected, even of a small percentage, they must in the course of a year amount to a very large sum. I believe this matter was dealt with in a paper by Mr. J. H. Rider some years ago in connection with a description of the London County Council Tramways.[*] I believe that was the first occasion when the purchase of fuel on a calorific value basis was advocated before this Institution. There are, however, a number of difficulties in purchasing fuel on that basis. In the first place I do not know of any colliery in this district, although they have been approached on many occasions, which would be prepared to enter into contracts to supply fuel on such terms and conditions. I admit that the manner in which fuel is usually bought is not fundamentally sound, because many points arise in connection with the grading of fuel which seriously affect the value of the material to the purchaser. The author has drawn particular attention to moisture and the ash. I should like particularly to offer a few comments regarding moisture. Perhaps I should preface what I have to say by pointing out that the author's remarks deal almost entirely with coal which is sea-borne. Of course such conditions do not obtain in this district ; all our fuel is brought by rail or, to some extent, by canal. The percentage of moisture will vary very considerably with the same quality of coal, particularly if we are purchasing what is known as washed fuel. In some cases the percentage may rise to 14 or 15 per cent. If we allow it to remain in the railway trucks for some days during the summer, for instance, when we weigh it there will be 7 or 8 per cent difference in the moisture compared with what it would have been had it been weighed sooner. Such being the case, it is clear that differences of opinion and disputes might easily arise between the purchaser and the seller. Washed fuel, of its very nature, must be subject to considerable variations in the percentage of moisture which it contains. Then in regard to grading fuel upon

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[*] *Journal I.E.E.*, 1909, vol. 43, p. 235.

[illegible] I had hoped that the author would offer a few [illegible] in regard to the different sizes rather than [illegible] I was using the word "small." The grading has considerable effect on the value when the coal is burnt. For instance, it is obvious that even the very [illegible] cannot be as [illegible] Grading in sizes therefore has considerable influence on the value of the fuel. In my opinion any specification such as that suggested should make some provision for dividing the fuel into certain definite sizes, starting perhaps in the case of washed fuel from 1½ in. and going down to something like ¼ in. or even smaller. This is important, and I think attention should be called to it. On the question of ash, I entirely endorse the author's remarks to the effect that the quality of the fuel, even from the same colliery, varies appreciably from wagon to wagon, from shipload to shipload, and from day to day. Speaking with a layman's knowledge of colliery working there does not appear to be any reason why this should happen, but we frequently have to discuss the matter with the colliery people in order to keep them up to the standard.

I turn now to the author's remarks on laying cable conduits. There cannot be any question that for densely populated districts with expensive underground excavations it is essential that draw-in systems should be adopted, solely because of the cost of getting at them. In other cases, however, I think that a cable laid on a solid system would, on the whole, give rather better results. The author described a case where he went from trouble to trouble until he got down to 40 ft. or more. Such cases are not often met with; otherwise the cost of cable-laying and even the cost of supply might be considerably higher than it actually is. Of course in connection with any contract of such an extent as that mentioned in the paper, provision must be made in the contract itself for dealing with the cost of special work. The author made a remark to the effect that they had found it advantageous in contracts such as this to select or to allow for certain lengths of extra difficult work to be included in the total contract price rather than to make provision outside the contract itself by means of a schedule. That is a valuable suggestion and one which some of us may deem it desirable to adopt in framing future contracts.

[illegible] My experience of specifications is fairly wide and I quite agree that the best method of drafting them is that defined on page 364, i.e. to define the conditions and results to be obtained, leaving the contractor to meet the requirements with his standard products if and when they are suitable. When I observe the lengths to which some engineers go in drawing up the [illegible] policy of accepting the lowest tender. Unfortunately in [illegible] forced. If an engineer recommends anything but the [illegible] committee seems to think that he is [illegible] into his pocket. That is utterly untrue. [illegible]

Mr. J. A. Robertson: While it is true that no engineer would attempt nowadays to issue detailed specifications for turbo-alternators or rotary converters, it is still necessary to define very clearly the performance of plant and to specify the nature of the tests for ensuring conformity to the specification. I am sorry the author has not dealt more fully with this subject. He raises a contentious subject in referring to conditions of contract. The contract conditions which the purchasing engineer formerly attached to his specification cannot of course be defended, but the British Electrical and Allied Manufacturers' Association have swung over to the other extreme in what are known as the "Beama" conditions. The fact that these conditions with only slight modifications are identical with those of the Institution has not improved matters, and the Incorporated Municipal Electrical Association representing the largest body of purchasing engineers in this country has not yet accepted them. I agree that if the engineer is allowed to select only firms of "known excellence and ripe experience" as contractors the results will generally be satisfactory, but we must take care that the smaller firms are not extinguished, otherwise purchasing engineers will be restricted to one or two firms and standardization of designs may lead to standardization of prices. The author seems to have been somewhat unfortunate with his switchgear. In a large undertaking with many substations the purchaser may standardize switchgear, but in most cases the design had better be left to the manufacturer's specialists. It is a pity that there is no standardization of ideas regarding switchgear. When we find one firm emphasizing the fact that they allow 6 in. clearance between metal parts in substation switchgear, while another firm considers 2 in. clearance to be sufficient for the same duty, the purchasing engineer has to take a resposibility which ought not to be necessary, and the evil is greater in those cases where the lowest tender is still regarded with favour. With regard to coal specifications, most of us are glad at the present time to be able to purchase coal of any kind. One thing is certain, that if onerous conditions regarding calorific value are applied the contractor will cover the risk by adding a percentage to the price. In this district collieries refuse to accept any conditions which vary the price of coal according to calorific value.

Mr. S. Ferguson: A manufacturer should not be required to read through a lot of superfluous matter when preparing a tender. For general conditions reference should be made to some well-known standard conditions, for example those proposed by the Institution, thus preventing tenderers having to refer to them specially. One of the most important points in these conditions is the terms of payment. Municipalities could help manufacturers considerably if they could delete the 10 per cent retention money on small contracts, say for less than £500. [illegible] in relation to his capital, he can very quickly get a large proportion of his capital locked up in retention money. These accounts involve more clerical work, and retention money seems to me quite unnecessary for small contracts. It is interesting to note that for quite large Government contracts [illegible] full payment has been made after final test. With regard to technical requirements, I think that switchboard specifications should be either (*a*) complete in

Ir. erguson.

every detail, and include drawings or diagrams, or (*b*) a mere statement as to the plant to be controlled, leaving the manufacturer to offer the most suitable gear. With the latter arrangement it is somewhat difficult for the purchaser to compare the tenders when received, but I feel confident that this method is better than an incomplete specification which is capable of misinterpretation. If an engineer has to prepare a switchboard specification, say, once in 6 months, he cannot be expected to remember all the items he may require, such as indicating instruments, recording instruments, integrating instruments, voltage-control apparatus, circuit-breaking apparatus, protective devices, etc. The manufacturer has these things at his finger-ends, and if he knows the plant to be controlled, can offer the most suitable apparatus. There is one important important item which is sometimes omitted from specifications, and that is the current density in current-carrying apparatus. If it is left open then different manufacturers will offer different densities, so that the tenders are not comparable. When calling for oil switches for generating stations, it is very necessary that the inherent reactance of the generating plant should be specified. I find this is very seldom done, although it is a vital factor in determining what breaking capacity of switch is necessary for the particular duty. I have known these reactances vary from 2½ per cent to 15 per cent, so that the duty imposed on the former switch would be 6 times greater than on the latter switch with the same capacity of plant. With regard to the system of inviting tenders outlined by the author, I do not think this is generally liked by manufacturers. One important objection is that manufacturers are not allowed to use their standard apparatus but are required to conform to the designs furnished by the purchaser. Every manufacturer who undertakes a contract will have to make the special tools required for the manufacture of the particular apparatus, and it seems to me a considerable waste of labour. Furthermore, it is quite conceivable that the purchasers' designs may very quickly grow out of date, and advantage would not be taken of the progress which is continually being made. A better plan would be for the purchaser to make up his mind that certain standard types of apparatus, made by certain manufacturers, best suit his requirements, and to specify the same. The manufacturer would, from time to time, embody any slight improvements which are made, but which would not destroy the interchangeability of the apparatus. I believe this arrangement was adopted by the London County Council in the case of circuit breakers. Very frequently specifications call for apparatus which is considerably out of date, and they may thus cause a manufacturer considerable trouble in complying with the same. Take, for example, Government inquiries for switchgear; these usually call for magnetic blow-out circuit breakers, also knife switches, the hinged contacts of which do not carry current. Both these requirements have been abanboned by most leading manufacturers. The author seems to have had considerable trouble with his switchgear in the early stages, and I should like to have his confirmation that blow-outs were finally deleted on the circuit breakers in the substations. Finally there is the bill of quantities. This is now very rarely included in specifications. One difficulty experienced is to get the items so concise and complete that there will be no misunderstanding as to which item sundry apparatus is to come under; otherwis difficulties will result if the quantities are to be increased or decreased. Mr. Ferguson.

Mr. Kidd. Mr. W. Kidd: It is certainly most desirable that all tenders should be brought to a common basis. The author mentions two methods, namely, either to specify one's requirements in detail or simply to ask for certain results. It is most desirable in many cases to take an intermediate course. The purchaser has to consider the men who will have to operate the plant, and the temperament of such men apparently varies in different districts. Again one has to bear in mind what is going to happen after the contract has been let. If we leave the specification open we shall have a lot of correspondence afterwards; the contractor will write and ask about various details and want to know whether they will meet our requirements or not. I think in a specification which is carefully and thoroughly drawn up a lot of that should be avoided. It may be a case of asking for position of terminals and the size of the cable proposed to be used on motor-generators, transformers, etc. That is no reason why these particulars should not be given in the specification. Again, the purchaser should certainly state very clearly what guarantees he wants and under what conditions the guarantees have to be obtained. It is rather annoying sometimes to go to witness a test or check over a test sheet and then to find that a particular item has been omitted both from the specification and from the tender. I think purchasers should specify that curves showing the effects of variation of such matters as steam pressure, vacuum, etc., in the case of turbines, and temperature and humidity of atmosphere in the case of cooling towers, on the results of the tests should be submitted with the tender. Otherwise of course it is difficult to see whether or not the guaranteed result is obtained. One must also, I think, specify what method is to be adopted in testing. Take circulating water pumps, for instance; is the water to be measured over a weir or by the difference of condenser inlet and outlet temperature? If we adopt different methods we get different results. Then there is the vexed question of erection. Trouble frequently arises from insufficient information being given regarding the accessibility of the site, use of tackle, builder's work, etc. In all power stations pipework occupies a very prominent position. I certainly think that in this case the purchaser should issue a detailed drawing of the pipes and supports and accept full responsibility for the run of the pipes. It is not fair to ask the contractor to come to a strange place to measure up for the run of pipes; he is only human and will make mistakes. A great many of the troubles which arise in connection with the installation of pipes would be prevented if the purchaser supplied proper details in the first instance. The tendency in manufacturing works nowadays is to do all design work in the office and leave the works to manufacture the apparatus. That is, I think, a movement in the right direction and should be applied to pipe contracts instead of leaving the erector to design supports. The author proposes that large power stations should standardize their substation switchgear. I quite agree with him there. When we have to extend the switchgear we find a great difficulty unless we have standardized the general arrangement, principal dimensions, etc. I do not agree that the purchaser should design the switches and [illegible] conformity with the regulations or are not satisfactory [illegible] temperature rise to guard against bad workmanship and fitting. Mr. Robertson has mentioned a case of a 2 in. clearance for 6,000-volt switchgear; that is not enough. I should go further than the author and not only standardize sub-station switchgear but also the performance of transformers, so that any one transformer will parallel with any other. The difficulty with the transformers comes in when we want to extend the substations; if we have not standardized the transformer performance we have a difficulty in getting another transformer to parallel with the original one. In Manchester we have a range of transformers rated at 250–500 k.v.a. and 1,000 k.v.a. so designed that any one can be paralleled with any other. I wonder how many purchasers ask the contractor to state what are the power factors of the motors. I am afraid there are very few. In two cases which have recently come under my notice the consulting engineers have specified that all the motors for the equipment of certain factories should be of one size for the sake of interchangeability. The result is that many of the motors are only half loaded and the effect is a bad power factor for the supply system. This question of power factor is becoming a very serious matter to electric supply authorities. I am rather sorry that the author has made no mention of the work done by the Engineering Standards Committee. The Reports that the Committee have issued are certainly very valuable to anyone who has [illegible] present; both the engineer and the manufacturer would [illegible]

Mr. J. Frith: I agree with Mr. Robertson's criticism of the "Beama" conditions; they are certainly not to the advantage of the purchaser, and I am equally sure they are not, in the long run, advantageous to the manufacturer. [illegible] cient to state what one wants and then leave it to the [illegible] render certain methods of manufacturing unsuitable. For [illegible] that the lower [illegible] power plant testing, and [illegible] contains the latent heat and an allowance for heating the water to the boiling-point. They might have chosen a figure which was rather simpler for arithmetical calcula- [illegible] lower calorific value really means. It is an admission that we cannot afford to condense the moisture in the flue gases. To take the higher calorific value in working out thermal efficiencies is to assume that the plant might have condensed the moisture in the flue gases, which is something we are particularly careful not to do; hence the lower calorific value should be used. With regard to the clause in the specification making the price of coal lower as the moisture increases, this seems to mean that the author would be equally pleased to buy 10 buckets of coal and pay for 10, as to buy 9 and pay for 9 and then pay his men to throw a bucket of water on the fire. This is not scientific, though it may be sufficiently good for commercial use and it certainly has the merit of simplicity.

[illegible] I believe that the specification issued by the London County Council Tramways Department for the purchase of fuel on a heat basis was the first instance of the adoption of this method on a large scale in England; though, according to United States Bulletin No. 116 of the Bureau of Mines, 50 per cent of the purchases on behalf of the United States Government are made in a similar manner. I am aware of the difficulty of purchasing direct from collieries on a calorific basis, and of course at the present time coal is in such demand that the purchaser has no option but to take what is offered to him and accept the colliery proprietor's conditions. It would be interesting to know if the 7 or 8 per cent difference in moisture between summer and winter is an ascertained figure or only a surmise. If it really exists, it appears to be an excellent argument for purchasing fuel on the basis described, otherwise one is paying for an indefinite amount of water at the price of coal. Mr. Watson will find that the size of small coal is given in the paper. The smaller size of fuel is that which will pass through a mesh ⅜ in. square, whilst the larger size is usually screened through 1-in. mesh. With respect to the percentage of small coal and troublesome litigation, 10 years' experience has given rise to neither one trouble nor the other. Although, generally speaking, cable ducts were laid with a cover of about 2 ft. 6 in., owing to serious obstructions a depth of 40 ft. was necessary in certain cases before a clear way could be found, but such depths were of course strictly limited, otherwise cable- [illegible]

[illegible] fications strictly defining requirements and leaving the manufacturer to put in his standard plant. While such [illegible] ence with turbines will bear out this statement very forcibly. Whilst I cannot altogether agree with his [illegible] in municipal work that there is extreme difficulty in accepting any tender but the lowest.

Mr. Robertson regrets that I did not enter into a detailed discussion on the performance of plant, including turbo- [illegible] required at least a dozen papers to do justice to the various subjects. Personally I have no objection to the Model General Conditions issued by the Institution, and I agree with Mr. Robertson that open tendering and the general acceptance of the lowest tender has the advantage of encouraging smaller firms, who otherwise would have but little chance in obtaining larger contracts. With regard to the experience with switchgear outlined in the paper, the troubles occurred through accepting standard apparatus for conditions of more than ordinary severity. Since substation switchgear was purchased under the conditions described in the paper, no trouble with such gear has been experienced, and Mr. Robertson's own remarks show the necessity for accepting something more than the various standards of different makers. For instance, with switchgear for 6,600 volts a clearance of 2 in. to brickwork is distinctly small and not less than 4 in. clearance should be adopted, whilst 5 in. or 6 in. is even better. There is no hard-and-fast rule as to the maximum distance except that the greater the clearance, up to say 6 in. (for 6,600 volts three-phase), the safer is the gear. Mr. Robertson's remarks on the purchase of fuel have, I think, been covered in my reply to Mr. Watson.

Mr. Ferguson's remarks are practically confined to switchgear, and I quite agree with him that clearness and conciseness in specifications should be more general. With respect to the terms of payment, if standard apparatus is purchased, such as knife switches, circuit breakers, or instruments, the payment should be a cash one on delivery and completion of tests. If, however, the contract is of a more extensive character and includes a maintenance period, the payment of the retention money does not become due until such maintenance period has expired, and of course this period should be limited to a reasonable time. With respect to technical requirements, if large purchases are to be made, it is better in every way to issue detailed drawings and purchase the particular type of apparatus that has been found most suitable for the purposes required. If, however, as is generally the case, purchases are moderate in amount, it is better to purchase standard apparatus suitable for the work in hand. I quite agree that the switchgear manufacturer is better prepared than the purchaser to design suitable switchgear. On the other hand, stress of competition limits his power in this way. Whilst on the one hand he would no doubt be pleased to make and sell nothing but the best and heaviest type of switchgear, severe competition forces him to install switchgear of a much lighter and flimsier description, and it is with gear of this character that so much trouble has been experienced when connected to large power systems. With respect to reactance, so small a figure as 2½ per cent cannot apply to modern generator circuits; 10 to 12 per cent is more like the figure. In reply to Mr. Ferguson's question, two types of circuit breakers have been largely used—air break and magnetic blow-out. Whenever there is sufficient room for the air-break type, that is the one preferred, but owing to restricted head-room the magnetic blow-out must sometimes be used. With respect to Mr. Ferguson's closing remarks, a bill of quantities should be attached to every specification; otherwise it is difficult or impossible without prolonged negotiation to alter, extend, or restrict a contract.

The views of Mr. Kidd, who I understand is in the purchasing department of the Manchester Electricity Department, in general agree with those expressed in the paper. With respect to pipework, this should generally be designed by the purchaser, and necessarily so in the case of extensions to an existing station where running plant requires to be negotiated. I quite agree that the specifications issued by the Engineering Standards Committee should be used to the greatest possible extent, and I invariably adopt them where possible. Having served on the Standards Committee I am of course aware of the care devoted to the preparation of such specifications, and it is to be regretted that the scope of the Committee's work is not extended further.

In reply to Mr. Frith, the coal purchased had its calorific value determined from dried samples, and the conditions mentioned by him do not apply. Such conditions have reference to boiler-testing and really depend upon whether the steam generated from the moisture in the coal is or is not condensed on the heating surfaces of the boilers or economizers. In regard to Mr. Frith's picturesque description of buckets of water, it is obvious that water must be allowed to a certain extent in any commercial purchasing, and the figure of 10 per cent is in my opinion a reasonable one to take, bearing in mind that for Scotch washed nuts the moisture varies from 9·5 to 16·9 per cent and for Yorkshire washed nuts 3·25 to 10 per cent, taken over a series of years and for many cargoes.

In conclusion I would point out that the purchasing of coal on a calorific basis, which has been so generally criticized, has stood the only test which is of any value in practical life, namely, the test of actual experience, and for 10 years it has enabled coal to be purchased on a large scale by open competition and without a single dispute with respect to quantity, quality, or price. In fact the only disputes which have arisen are those of delivery within a specific period, or of the berthing conditions provided for the steamers. Of course local conditions may alter the possibility of buying fuel in this way, but under the conditions described the method left little to be desired.

Scottish Local Section, 3 April, 1917.

Mr. A. Page: I agree with the author that in the majority of cases engineers should specify exactly what they want when purchasing plant, as manufacturers' standard apparatus—particularly in the case of auxiliaries —very often has undesirable features. In the case of a turbo-alternator, for example, the vacuum required is generally stated, but there is seldom any particular reference to the capacity of the air pump to maintain the required partial air pressure in the condenser. The gauge fittings and drain valves at the high-pressure end of the turbine are almost certain to be of gunmetal unless specified to be of steel. Thermometers on the condensing plant will not be supplied unless specially asked for, and the general absence of instruments means that the operating engineer is constantly at a loss in diagnosing the cause of unsatisfactory working. If the maximum [illegible] transformer construction is mechanically unsound; and [illegible] a special manner there will be frequent break- [illegible] point of view only. Transformer oil is another case in point, trouble from sludging being quite common. There are innumerable other instances which one might quote showing the necessity for carefully specifying what is required to meet the conditions. I consider technical information provided by the firm submitting a tender to be an essential feature of the specification. If full information of this nature were asked for and supplied it would often save a great deal of time and correspondence when deciding which offer is to be accepted. The Model General Conditions of the Institution could with advantage be altered somewhat, as it has been our recent [illegible] manufacturer. In the case of complicated machinery I think it is quite out of the question to expect an engineer to issue a specification which will always ensure that the lowest tender can be accepted. The coal specification [illegible] with the purchase of a cargo of coal, but it would be rather unworkable when the coal came into the works in wagons from a large number of different pits. The author prefaces his reference to cable-conduit specifications by a statement that in large towns the solid system is unsuitable. This is certainly not the case in Glasgow, where the cables have to be carried along routes in the neigh- [illegible]

Mr. [illegible] manufacturers in reading through the different forms of general conditions issued by the various municipalities and companies, and I hope that a standard form of conditions will soon be adopted which will be satisfactory alike to the manufacturer and the purchaser. Regarding [illegible] it is certainly necessary for the [illegible] obtain, but I think that to [illegible] ted for, but where [illegible] nsformation of energy, the [illegible] steam pressures and high superheat are going to be the [illegible] I think that a great deal of the loss in most stations is at present due to the prime movers being too far away from the boilers. Perhaps the ideal arrangement would be to place the turbines on top of the boilers and the generators in another room so as to be away from the heat of the boiler house. I admit that there might be some difficulty in finding room for the condenser. At any rate it seems to me that the more compact we can make the plant the less loss will there be in transformation. Regarding the purchase of coal, the author seems to think it is a matter for the purchaser alone to decide whether he should purchase fuel on the B.Th.U. basis or not, but I can state that the average colliery proprietor—in Scotland at any rate—will not consider that method. He can usually sell without such restrictions all the coal that he is able to raise. The best solution from the purchaser's point of view is to obtain an analysis of all the coal which he is likely to buy, or, better still, test the fuel under actual working conditions. He can then compare the relative merits of the various fuels with the selling prices.

Mr. Morgan.

Mr. W. D. N. Morgan: Most of us here are continually interested in the question of coal purchase and, as has been said by the author, many of the fuel purchases in America are based on calorific value, payment being made on the result of chemical analysis. In this the U.S.A. Government have done much, the greater part of their requirements being dealt with in this way. The method is more suited to conditions where the quantity per delivery is large, and less so when small lots are delivered as by rail. Some years ago I examined the problem of purchase by analysis, but found that our colliery owners had not generally advanced far in this direction and looked upon the method with disfavour. My own experience has been that it is better to purchase supplies from collieries adjacent to one's works, and by actual test under the boilers and checked by chemical test determine for oneself the relative values of the coal drawn from the various pits. In this way a very clear guide can be obtained of which fuel to buy and what price should be paid for it. Should the quality of the coal fall off I have not hitherto found difficulty in arranging matters with suppliers. It will be found that the fuel of the highest calorific value for the price, taking everything into consideration, is not necessarily the most economical; and if the relationship of the coal cost at the pit to the railway rates existing prior to the War is materially altered, the whole question will have to be reviewed in relation to the class of fuel that may best be used. Turning to specifications for, say, switchgear, there is a very real danger that, by specifying in great detail how the work is to be done, progress and development may be delayed in that the contractor having no responsibility for the performance, provided the workmanship is good, loses the incentive to advance design, and it is, generally speaking, the contractor who has the greater opportunity of becoming a specialist in the apparatus he is turning out. There are, of course, exceptional cases, such as the development of a power supply system which necessitates a number of gears to perform the same duty. Then the purchaser, profiting by the experience of gear already [illegible] in a better position than the contractor to know what will best suit the case.

leod.

Mr. D. M. MACLEOD: The author rightly insists upon the importance of the General Conditions of Contract. I consider such conditions to be an essential part of all specifications, otherwise the purchaser might unknowingly incur very heavy penalties owing to the use of patented apparatus and to such contingencies as the contractor finding himself unable to implement his contract. It is extraordinary that while most engineers recognize the importance of drawing up a clearly worded specification for capital plant, only a few take the trouble to extend this system to cover consumable stores, which in my opinion is quite as important in many respects as a specification for capital plant. I think it is to the credit of most public bodies in this country that they have recognized the importance of including specifications for stores. The author refers to the question of vagueness in specifications. Sometimes specifications are left purposely vague. The author's remarks in regard to coal purchases are very instructive. Probably there is nothing more unscientific than the manner in which coal is usually purchased, unless perhaps it is the manner in which it is used. When we consider that the annual output of coal in this country ranges from 260 to 300 million tons per annum, we can see at once the importance of trying as far as possible to economize in our natural wealth. A great many engineers in this country seem to have been influenced to a very large extent by the supposed economy effected by using small coal. One can understand such coal being economical a number of years ago when colliery owners were only too pleased to get rid of it for 5s. or 6s. a ton, but when one has to pay something like 15s. a ton for small coal it will be found that there is greater economy in purchasing large coal and crushing it down to make it suitable for one's grates. The Clyde Valley Power Company have made fairly extensive purchases along these lines for years past, and the results are very gratifying. With regard to the cables for distribution, I wonder why the author has not referred to armoured cables laid direct in the ground. This type of construction is largely adopted now, particularly in rural districts. When one has to carry out work in remote country districts the question of carriage becomes serious, and by the use of armoured cables great economy is effected. Finally, I think there is no doubt that where specifications are drawn up by skilled engineers who know what they want and insist upon getting it, nothing but good can result.

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Mr. J. M. M. MUNRO: The clause which the author does not like, namely, that "notwithstanding any errors or omissions, the things omitted shall be deemed to be included as though specifically mentioned," may appear unfair in a contract, but it saves much needless detail. No man can specify every item of construction, nor can he provide clauses against every contingency and possible trick of trade. Hence the need that the engineer should reserve to himself somewhat wide and arbitrary powers. In the end, contractor and client alike must trust their engineer. If he cannot be so trusted he is of little use. One of the benefits of having a competent and reliable engineer is that any tender, even if the lowest, can be safely accepted; yet consulting engineers should not cease to ask for a big measure of freedom when the choice of a tender, not necessarily the cheapest, and not necessarily from the firm of biggest repute, is to be decided. But once this principle of freedom is acknowledged, the wise engineer will immediately set himself to limit that freedom as rigidly as his specifying skill will permit. In some things he can almost succeed. In coal, for instance, as we have seen from the examples given by the author—though even here (in second column of page 365) he mentions one point which may set a limit to slavish adherence to the rule of accepting the lowest tender. In the paper it is stated that "this method of buying coal is unique." I do not suppose that this is intended to mean that the method is suggested for the first time. I believe that Glasgow buys or tried to buy its coal on a thermal unit basis. They at least specify the minimum thermal units which they are going to accept, and they doubtless put a value, when comparing tenders, upon the thermal value guaranteed for each class of coal. The author mentions that he reduces his tenders to the common denomination of a normal coal. I should like to know if details of this standard are stated in his specifications, as well as the minimum values acceptable. Another thing in following the process of fixing a basis of price is that it would be necessary, every time that a sample was taken for a test, to have a corresponding sample laid by, sealed and marked. This would be useful in the event of dispute and arbitration. Would it not be worth while to have all the samples taken and tested by a neutral party agreed upon by both sides? This is certainly the ideal method of buying coal and I am surprised to hear, from the experience of those who have been buying large quantities, that the colliery people refuse to countenance the principle of payment based on heat value of coal actually supplied. As regards the laying of cable conduits, there is apt to be difficulty even if the author's schedule is very elaborate and complete. There is often a fine line of distinction, as between different degrees of hardness of rock for example, between items of widely differing price. The more probable differences can be described and made subject to easy test. As for the rest, here again reliance must be placed on the fairness and common sense of the consulting engineer. I cordially agree with the author's general remarks in the closing paragraph of the paper.

Mr. Munro.

Mr. Stothert.

Mr. J. K. STOTHERT: If contractors were always honest, possibly general conditions and stringent clauses in specifications would not be required, but it is certain that the requirements of the purchaser must be made known before the contractor can get out his bills of quantities and prices. I agree with the author that specifications should be drafted in the simplest language, and that general conditions imposed by legal minds, which can only be understood by a mind of this description, should be avoided in order to save complications and possibly law-suits. I thoroughly agree with the author with regard to the "omissions clause," which is sometimes found in specifications even to-day, and I am somewhat surprised that Mr. Munro should defend this clause. The purchaser's consulting engineer should surely know what he requires better than the contractor can possibly do. All that a contractor should have to do is to price his bills of quantities, and he is just as liable as the engineer to make an omission on some point which is not clear from the drawings or specifications; moreover, if he accepts the omissions clause, the contractor has to suffer the financial penalty, which is not the case with the consulting en-

[illegible] little details, and therefore it is more satisfactory to quote to a schedule prepared by either the contractor or the consulting engineer. It is sometimes specified that the engineer shall be the sole arbiter, that the plant shall be to the engineer's entire satisfaction, and shall be first class in every particular. If such conditions are accepted and the contract is proceeded with, then trouble is in store, because no contractor in making out [illegible]ld possibly say what the sole arbiter might consider first class, and what would entirely satisfy him. Any contractor of experience would insist upon an arbitration clause, and that the word "entire" should be replaced by the word "reasonable." The consulting engineer should not be the sole arbiter. In my opinion his duties are to hold the balance between the contractor and his client, and after many years of contracting, I have come to know that the more experience a consulting engineer has, the better it is for both the contractor and his client; for he does not, if he is wise, place his contracts with a contractor who is likely to be "full of tricks" and who endeavours to defraud the purchaser in petty ways which will put a few pounds into his pocket. Although with some classes of material it might be practicable to make a rule that the lowest tender be accepted, in general I think there is a danger in doing so. It would be necessary that all the tenderers should be known to be men of experience in the particular kind of plant which it is intended to purchase. With regard to the method of buying coal at its calorific value, I agree with Mr. Page that it is impossible in this district to get the coal suppliers to tender on this basis. I should like to know the author's method of arriving at the calorific value of the fuel—how the fuel is sampled, and who fixes the calorific value at the time of purchase. It would also be interesting to know where the coal is weighed. If it [illegible]d at the central station, the [illegible] wet weather is very considerably increased, as well as the weight.

[illegible] that specifications are necessary in connection with engineering projects, I am afraid I am out of sympathy with the spirit which has induced the British Electrical and Allied Manufacturers' Association and the Institution [illegible] and conditions are concerned, is reasonably met by the ordinary British sense [illegible] country. If either of the parties to the bargain lacks reasonable honesty, then I am not aware of any set of terms and conditions which would effectually protect the [illegible]rse to independent arbitration. I [illegible] this desire for standard terms and [illegible] the purchaser [illegible] tion, in the hands of a manufacturer, leaves a very big margin for interpretation. Coupled with this condition there is the fetish of imagining that the lowest offer is usually the one that can be readily accepted. With these conditions perpetual trouble will always arise. There is perhaps another fetish largely prevalent, but not generally acknowledged, which accounts, or has accounted, for a good deal of trouble, namely, that it is the purchaser's object to get more than £1,000 worth of goods for £1,000, or that in some way the object of obtaining tenders is to find some manufacturer who is either a philanthropist or a fool.

Mr. P. HUTCHISON (*communicated*): As there seems to be a great diversity of opinion in this country in regard to the benefits to be derived from the issue of specifications, it may perhaps interest members to hear of a country where the practice is non-existent. I have resided for a number of years in China and the kind of enquiry we receive is as follows: a feed-pump for 200 kw., a boiler for 3,000 lamps, or a steamer "all the same you build before time but more big." China is a country that would benefit greatly by the employment of consulting engineers and the issue of simple specifications, but the Chinese resolutely refuse to utilize their services. In connection with the author's remarks on specifications for coal, I call to mind a small electric lighting plant in England where considerable trouble was experienced owing to variations in the quality of the coal. The engineer decided to make the coal contractor jointly responsible for the units generated: a meter was put in a small house and two special locks were put on the door, the engineer keeping one key and the coal contractor the other. At regular periods readings were taken in the presence of both parties, and the coal contractor was paid on the records. The first year's contract was made at the rate of 0·38d. per unit generated, and the second year was taken at 0·34d. per unit, so I assume that the contractor was quite satisfied with his bargain.

Mr. J. SHEPHERD (*in reply*): In reply to Mr. Page I am afraid the ideal specification which he expected is one which no one can write, as no specification can cover correctly all circumstances. If he was thinking of general conditions only, there are those issued by the Institution which should find general acceptance, but even in the most limited form of specification drafting there is anything but general agreement. As a large purchaser of plant, Mr. Page generally agrees with me that a detailed form of specification is desirable from the purchaser's standpoint, and that is the universal experience of any purchaser of plant on a large scale, especially when such plant is required to work on a large power system. Whilst it is difficult to purchase complicated machinery on the basis of lowest price, such are the conditions of purchase of many public bodies; and the paper was an attempt to show how such conditions might be met. With regard to the purchase of coal by specification, I deal with this matter below, but the purchase of coal in this way when delivery is made [illegible] referred to in Mr. Page's concluding remarks was in no way in[illegible] at the time of purchase, and had such gear been worked on a smaller system or on lighting circuits, the trouble experienced would probably not have occurred; in other words, standard switchgear is not generally suitable for heavy duties resulting from large systems. With respect to the draw-in system of cable ducts, I understand that such a system is adopted in Glasgow for the tramway electrification.

I agree with Mr. Seddon that it would certainly be desirable for both purchasers and manufacturers to agree on an equitable set of standard general conditions, and it surely should not be beyond the wit of man to draw up a set acceptable to both parties. Whilst Mr. Seddon's remarks regarding detailed specifications may be true academically, they do not apply to various classes of manufacture where competition has in many instances forced a somewhat inferior article on the market, particularly in switchgear. With regard to the thermal losses in a station, the utmost efficiency in a well-designed station between B.Th.U.'s in the coal and units generated, does not, as a rule, exceed 11 or 12 per cent. The greater part of this loss occurs, not in the steam pipes, however, but in the turbine, and the bulk of the heat losses (from 50 to 60 per cent) is carried away in condensing water. With well-laid and well-lagged steam pipes, the losses in them can be made extremely small, and cases are known of highly superheated steam conveyed thousands of feet at moderate losses, the loss per thousand feet being about 2½ per cent in pressure and 6 per cent in temperature.

In reply to Mr. Morgan, the question of coal purchases I deal with below. With respect to the specification for switchgear, if the purchaser knows what he wants (and he ought to be the best judge) it is better for him to state his requirements in detail, especially if they are of more than ordinary severity, and I have no doubt whatever that Mr. Morgan would be of the same opinion had his experience been with large power systems.

In reply to Mr. Macleod, the demand for small coal has been so extensive of late that many users have found it economical to buy larger sizes of coal and to crush locally to a size more suitable for burning on mechanical stokers. In reply to his remarks respecting armoured cable, there is no doubt that this cable is, and will be, largely used.

In reply to Mr. Munro, I am afraid he will find that the clause respecting errors and omissions is not generally acceptable. Personally I do not think the clause is equitable, and the difficulties regarding small extras can easily be met in the contract by a provisional sum for the purchase of such extras as and when they arise. Generally speaking, the variation allowed for such extras is 10 per cent of the contract amount, but in large contracts 5 per cent is usually ample. With respect to the difficulty of accepting the lowest tender, this has not been experienced when careful specifications are drafted, and the practice of accepting the lowest tender has advantages as well as disadvantages. The question of coal is dealt with below.

It is certainly interesting to find that so experienced an engineer on the selling side as Mr. Stothert agrees so closely with the author regarding the general question underlying the drafting of specifications. The clause respecting errors and omissions I have dealt with already, and is one which need not give difficulty in practice. With regard to the engineer's requirements of "first class work" to "his entire satisfaction," there is of course the difficulty of definition, and agreement as to the meaning of "first class" and with his "reasonable" satisfaction, and there remains no entirely satisfactory solution of the difficulty especially when the contractor and the engineer meet for the first time on a contract.

Mr. Shepherd.

The conditions which Mr. Dixon outlines are, I conclude, those of a private buyer and are scarcely those discussed in the paper.

With respect to the general remarks that have been made regarding the purchase of coal on a calorific basis, several of the questions put are answered in the paper. There are generally two schools of opinion :—

(1) That the method of purchasing by analysis is satisfactory from a theoretical point of view, but it is too academic to apply in practice. To such opinion one can only say that the purchase in this way has been actually applied in practice for large supplies and for several years with satisfactory results, and I fail to see why the chief raw material for most electrical industries should be bought without reference to its chief and most useful constituent, and how long this is likely to continue with a commercial people is questionable, but there is no doubt whatever that in the future the purchase of coal will be of a more scientific character than in the past.

(2) The other school of opinion holds that the best method is to try varying samples of coal, and having met that which bests suits the local requirements, to purchase such fuel at a fixed price. Having regard to the varying quality of coal from the same pit and under the same conditions, and during a comparatively short time, it is somewhat extraordinary that with wide variation in quality, buyers are willing to pay fixed prices for varying qualities of fuel.

With specific reference to Mr. Stothert's inquiries, the value of the fuel offered was given by the merchant on his tender form when tendering, and was considered together with his price. The sampling was made by taking a shovelful of coal out of every 50 tons; the various shovelfuls were collected together and then crushed by a combined crusher and sampler. The coal was weighed at the station as delivered and the specification states how allowance for the moisture is made in determining the price. The question as to how long producers of high-class coal will be content to sell in competition with low-class coal without themselves wishing to sell on a calorific value, is a matter which only the future can determine. It is anything but uncommon to find purchases at fixed prices of coal having an ash content of over 30 per cent and a calorific value of less than 11,000 B.Th.U., and though such coal appears cheap to buy, it is anything but cheap to burn.

A NEW CONCENTRIC STANDARD DYNAMOMETER WATTMETER FOR HEAVY CURRENTS; AND CONCENTRIC NON-INDUCTIVE STANDARDS OF LOW RESISTANCE.

By A. E. Moore, Associate Member.

[illegible]

[illegible]

[illegible] experimental current coils, and their defects.

Pressure coils for use with concentric current coils.

[illegible]

[illegible]

Wattmeters for high, and for low power-factor measurements.

[illegible] power measurements. Advantages of concentric construction.

Use of reflecting concentric instrument as a standard ammeter [illegible]

[illegible]

Measurement of the phase errors in current transformers, and [illegible]

[illegible]

[illegible] amperes. The instrument was to be suitable for [illegible] [illegible] meters, and for any other refined measurements [illegible] for an instrument capable [illegible] was afterwards obtained. Previous to the installation of [illegible] [illegible] [illegible] neither of these [illegible]. In the [illegible]

[illegible] [illegible] ght-through [illegible] 100 amperes are un- [illegible] of phase with the main current, while the skin-effect may cause variations in the distribution of the current over the cross-section of the main conductors with changes in frequency, and this may consequently affect both the magnitude and the phase of the active part of the main-coil flux. It should be remembered that the active conductors of the pressure coil cannot be made to embrace more than a small portion of the main-coil flux, and for successful working this portion must always be a definite fraction of, and in the same phase as the whole flux. It is not very difficult to eliminate eddy-currents by avoiding the use of metal supports, etc., and having the main coils formed of stranded conductors, each strand being insulated; but in order that the current distribution may be maintained constant independently of changes in the frequency of the current, it is necessary that every strand of the conductor have the same time-constant (L/R). In the ordinary form of dynamometer wattmeter the main-current conductor is in the form of a coil of one or more turns, and there are many difficulties in the way of the satisfactory stranding of the conductor, if it is intended for currents of upwards of 1,000 amperes.

The theory of the dynamometer wattmeter has been very fully investigated already,* and the present contribution deals with a form of wattmeter in which the theoretical conditions are maintained in instruments for currents of upwards of 1,000 amperes.

In the wattmeter now to be described the author has made use of the concentric magnetic field which is formed between two concentric conductors when a current is maintained in them in opposite directions.†

If a wire be wound uniformly over the surface of a ring as shown in Fig. 1, the magnetic field produced when a current is maintained in the wire is symmetrical about the principal axis of the ring. So that every turn of the wire encloses the same magnetic flux, and, presumably, has the same ohmic resistance, and therefore the same time-constant. If all the turns are cut and their ends securely connected to copper end-plates (Fig. 2), the turns will be connected in parallel instead of in series, and the time-constant of any one turn will still remain the same as that of every other turn, since each will be of the same resistance and will embrace the same flux. Therefore if an alternating current be maintained in the coil thus formed it will be uniformly distributed over the turns, and the uniform distribution of the current will be unaffected by changes in the frequency. It is imperative that the winding be perfectly symmetrical, and in making up an actual coil many difficulties had to be overcome before a satisfactory construction was obtained.

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* [illegible]

† [illegible]

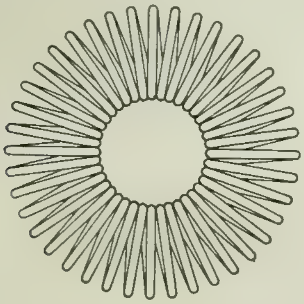


FIG. 1.—Closed ring winding; magnetic field concentric with axis perpendicular to plane of paper.

Fig. 3 illustrates how the pressure coils may be arranged within the current coil. Two coils are used in order to render the system astatic to uniform stray magnetic fields.

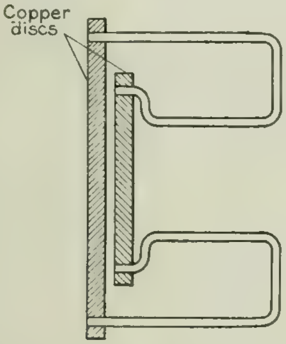


FIG. 2.—Sectional view showing how turns of ring winding may be arranged in parallel. Two turns only shown.

The magnetic axes of the pressure coils are nominally perpendicular to the direction of the flux produced in the main coil, and the result is a turning moment about a vertical axis.

CONSTRUCTION OF THE CURRENT COIL.

The difficulties met with in the production of a concentric-field wattmeter are:

(1) The construction of a current coil in which the phase difference between the flux and the current that produces it is negligibly small.

(2) The making of a mechanical joint in the current coil, which permits of the easy insertion of the pressure coils, but does not introduce a phase error in the current coil.

(3) The design and construction of the most suitable form of pressure coils.

Below are given descriptions of the various models with which the author experimented, and the defects found in them.

The author's first idea was to construct a system similar to that in the Kelvin kilowatt balance, but with a return conductor formed by an outer tube divided longitudinally into two halves and arranged concentrically with the inner tubes. The movable system could be made to have its axis of turning either horizontal or vertical, depending on whether it is intended to use a gravity or a spring control. Such an arrangement was not, however, adopted until recently.

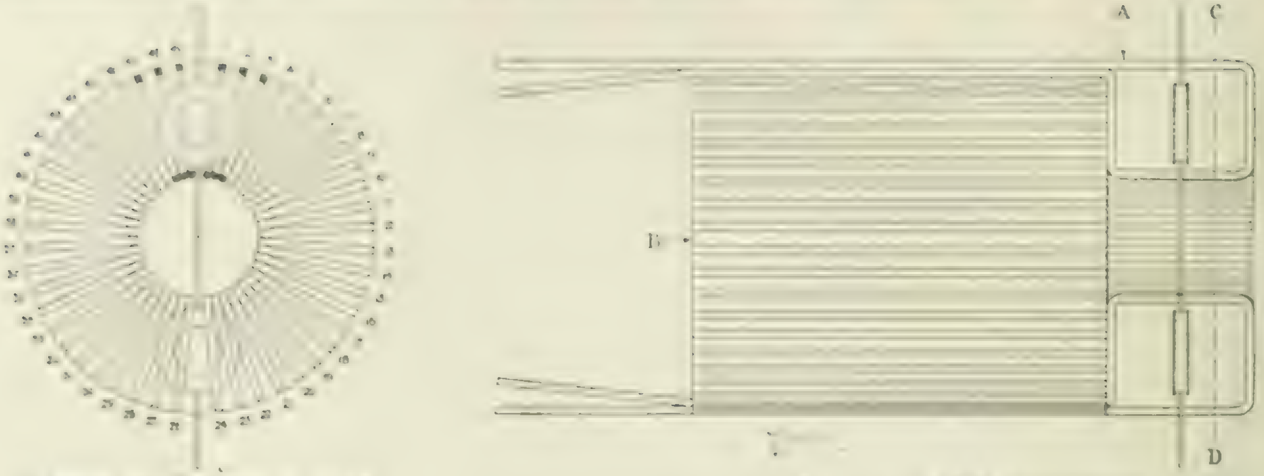
Model coil No. 1.—The first current coil made up is illustrated in Fig. 3. Fifty coils, each formed as shown at A, were made up from No. 12 S.W.G. cotton-covered copper wire, and these—or 48 of them—were mounted on a slotted wooden cylinder as shown at B. The ends of the coils were connected up to form four sets, each of 12 coils in parallel, and these four sets were connected in series with one another. Two of the coils, 25 and 50, were left out as shown, in order to admit of the insertion of the pressure coils. The ends of the 12 coils, which were connected together in parallel, were, in this case, brought together and soldered into cable sockets. The movable system consisted of two coils, each having an outside diameter of $1\frac{1}{4}$ in., and wound with 300 turns of No. 36 S.W.G. silk-covered copper wire.

The model was connected up in conjunction with the 100-ampere Duddell-Mather wattmeter in the manner described on pages 390 and 399, and the phase relation between the main current and the main-current flux in the author's and the Duddell-Mather wattmeters respectively, was compared at a frequency of 50 periods. The phase relation differed in the two instruments by 6 minutes (0·00175 radian), the flux leading the current in the concentric instrument. It may be mentioned here that the wooden cylinder on which the coils were mounted was, by a mistake, made too small in diameter. As a result the coils could not be placed around it quite symmetrically, and it was thought at the time that the small phase disturbance was due to this want of symmetry.

Model coil No. 2.—The next coil made up is illustrated by Fig. 4. Each of the 24 elemental coils consisted of two turns of No. 12 S.W.G. bare copper wire, and a thin silk ribbon was interlaced between the sides A of the wires to insulate them from one another. The ends of the coils were soft soldered to the copper end-plates B and C, and these end-plates were brazed on to the concentrically arranged tubes E and F. Connections were made with the tubes by means of heavy terminal blocks. The measured phase error in this case was 12 minutes, and the error was again attributed to want of symmetry in the coils.

Model coil No. 3.—The third coil is shown in Fig. 5. This was made up from copper tubes, the joints A and B being brazed, and the joints C and D soft soldered. Slots were cut in the tubes as shown in order to admit of the insertion of the pressure coils, which were slipped through the slots and then turned round. The measured phase error in this case was about 21 minutes, and it was evident that the coils were getting worse instead of better. It was therefore decided to try and improve model No. 1.

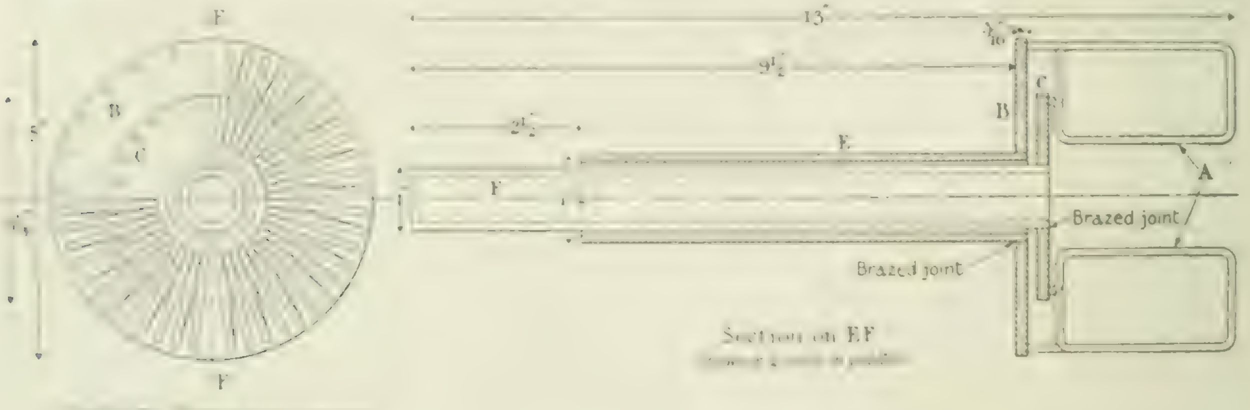
Model coil No. 4.—The coils were taken off the cylinder in model No. 1 and mounted on a new wooden cylinder made to the correct dimensions. The No. 2 model was taken adrift and the end-plates and tubes were used to connect up the ends of the coils on the new cylinder. At first



End view and Part section on CD

Side view [illegible]

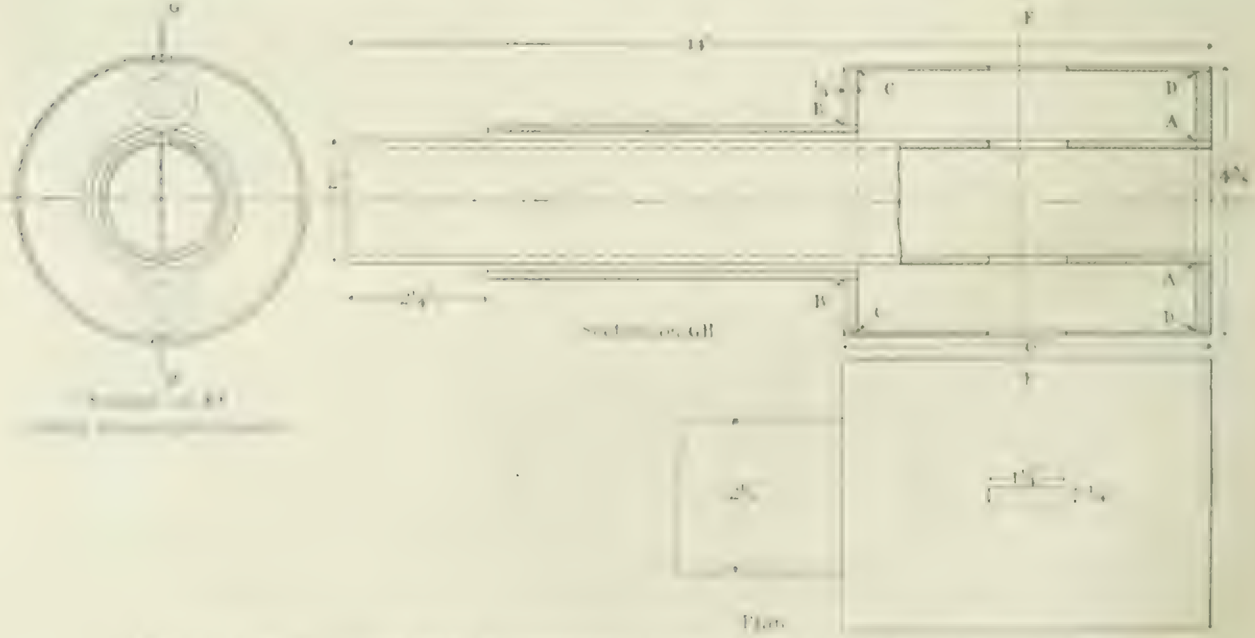
FIG. 3.—Current element for concentric wattmeter, made up of formed coils A, mounted on a slotted wooden cylinder B.



Section on EF

[illegible]

FIG. 4.



[illegible] made up of concentrically arranged tubes slotted to receive movable coils.

48 coils were put on the cylinder, spaces being left for the insertion of the pressure coils. On testing, the phase error was again about 6 minutes—flux leading relatively to the current—and it was thought that probably the trouble in all cases was due to the gaps left for the insertion of the pressure coils. It was considered that this defect might be eliminated by making each elemental coil a two-turn coil, connecting a turn near the gap in series with a turn remote from the gap. Thus, referring to Fig. 3, by connecting the following pairs of coils in series :

No. 1 and No. 37 and No. 13 and No. 49
2 „ 36 14 „ 48
3 „ 35 . . . .
. . . .
. . . .
. . . . . 24 and No. 38
12 and No. 26

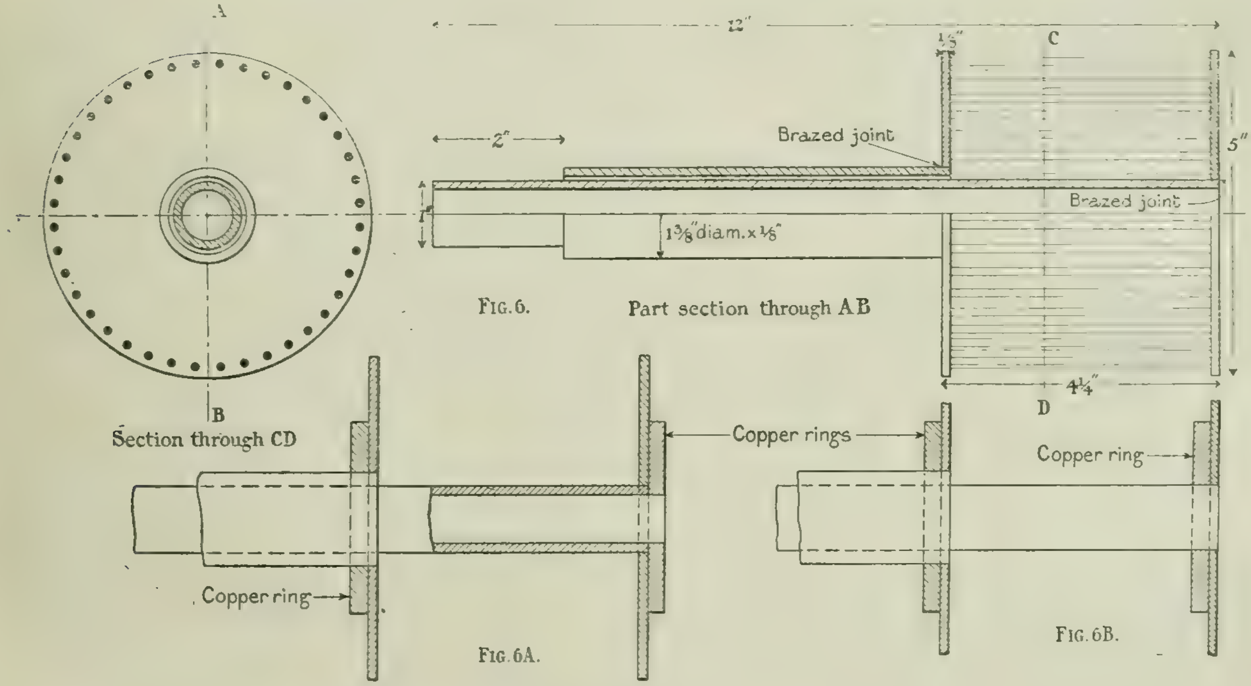


FIG. 6.

FIG. 6A.

FIG. 6B.

FIGS. 6, 6A, AND 6B.—Concentric current element with tubular inner conductor and wire-cage outer conductor.

On doing this, however, no better results were obtained. The connections were again arranged so that all the coils were in parallel, and the two coils which had been previously left out were now added. One coil only of the movable system was inserted, and on test a more satisfactory result obtained. However, on turning the current coil round and testing with the pressure coil between successive turns of the main coil, the phase error was found to vary, being zero in some places. At other places the flux was leading relatively to the current, and at others lagging.

Model coil No. 5.—An attempt was made to get a more symmetrical winding by using a tube for the inner conductor, and a number of wires placed symmetrically round the tube to form the outer conductor. It was thought that better results might obtain with tubular model No. 3 if slots were cut in the tubes all round at uniform intervals. This would have been a rather troublesome operation, so, instead, a new model was made as shown in Fig. 6. It was necessary to have some form of gap in the outer conductor in order that the pressure coils might be inserted, and in the model under consideration the wires forming the outer cage were spaced sufficiently far apart to admit of the pressure coils being passed between consecutive wires. Symmetry is thus preserved in the inner conductor by having it continuous, and in the outer conductor by having gaps at equal intervals all round. On testing for phase error the results were similar to those obtained with model 4.

At this point it was decided to overhaul the testing circuit thoroughly, and to eliminate anything which might conceivably affect the results. Further, it was decided to determine whether it was possible to obtain the desired result by using a comparatively long single conductor as the main-current conductor. For this purpose a standard tubular resistance of constantan, 24 in. long and 0·8 in. outside diameter, was chosen as the conductor, and the leads connecting to the tube were kept as far as possible in line with the axis of the tube. This tube did not give the desired result, and ultimately a length of No. 12 S.W.G. copper wire was substituted for the tube. It was concluded that with a wire of this size the testing current of 100 amperes could hardly distribute itself over the cross-sectional area otherwise than uniformly, and measurable eddy currents would be very unlikely. On testing, the desired result was not obtained, however ; but it was found afterwards that the defect in this case was due to the effect of stray magnetic fields from the main-current leads, as an astatic pressure coil was not [illegible] On substituting [illegible] pressure coil and re-arranging the [illegible] the stray field effect, quite [illegible] results were obtained with the No. [illegible] wire and afterwards with the constantan tube. Model coil No. 5, however, did not yet give satisfactory results even with the astatic coil.

Continuous current was next passed through coil No. 5, and by means of a reflecting galvanometer the drop of pressure on each of the wires forming the outer conductor was noted. These potential differences, of course, should all be the same if the current is evenly distributed over the wires, but actually they differed considerably, and this was found to be due to imperfect soldering between some of the wires and the end-plates. An attempt was made to remedy this defect by scraping the wires, but the attempt was not successful. New wires were substituted, particular attention being paid to the soldering into the end-plates. On re-testing for pressure drop in the wires, much more uniform results were obtained, but there was still a phase error with the coil. Next the potential difference between the inner tube and the end-plate was measured at different places, as indicated by *a*, *b*, *c*, etc., in Fig. 7. In this case the variation of the potential difference was found to be very serious indeed; and herein lay the greater part of the trouble. The deflections representing the potential differences on the wires were very nearly uniform, varying from [illegible] of the wires, the value most common being 135·5. It will be seen from Table 1, however, that the deflections representing the potential differences between the inner tube and the end-plate vary by more than 30 per cent. This, of course, was preventing the uniform distribution of the current in the inner tube. The phase difference between the main current and the main-current flux was measured at different points around the inner tube and the results are given in Table 1. It will be seen that the phase of the main-current flux varies relatively to the main current between [illegible]

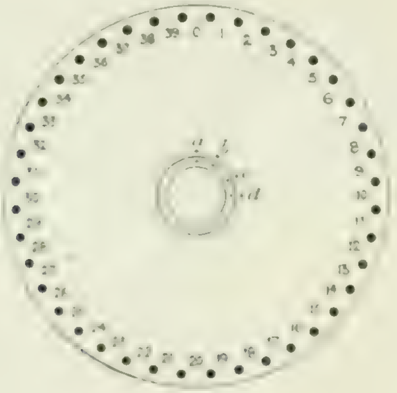


FIG. 7.

TABLE 1.

Phase Difference between the Main Current and the Main-current Flux inside the Cage, at Different Positions around the Inner Tube as shown by Fig. 7.

[illegible]	Phase Difference		[illegible]
	[illegible]	Minutes	
0	0·002	7 Flux leading current	15
4	0·0015	5 ,, lagging ,,	17
8	0·0035	12 ,, ,, ,,	19
12	0·0038	13 ,, ,, ,,	19
16	0·0038	13 ,, ,, ,,	16
20	0·0016	6 ,, ,, ,,	14
24	[illegible]	2 ,, ,, ,,	14
28	[illegible]	7 ,, leading ,,	12
32	[illegible]	10 ,, ,, ,,	13
36	[illegible]	10 ,, ,, ,,	13
2	[illegible]	0	16·5
27	[illegible]	0·7 ,, ,, ,,	14

As previously stated, the joints between the tubes and the end-plates had been brazed, and this was done in order that the wires forming the outer cage might be soft soldered in position afterwards without disturbing the joints at the tubes. It would appear that a brazed joint is not at all satisfactory for this particular purpose. For a trial, the end of the inner tube and plate were faced up, and rings of copper soldered on as shown in Fig. 6A. This did not prove satisfactory, but by taking the coil adrift and putting the ring on as shown in Fig. 6B, and paying careful attention to all joints, satisfactory results were at last obtained.

Model coil No. 6.—This is shown in Fig. 8, and was made up in such a way as to avoid, as far as possible, the defects of the previous models. It was evident that the resistances of the joints are comparable with the resistances of the tubes and wires, and the new model is designed to make the resistances of the joints as uniform and as low as possible. The coil resembles a squirrel cage and the instrument is spontaneously christened a "squirrel-cage" wattmeter by those who see it for the first time. The inner conductor is formed of a straight copper tube A, 1½ in. outside diameter and 3/16 in. wall. The outer conductor is formed of 40 No. 10 S.W.G. copper wires arranged symmetrically around the inner tube. The ends of these wires terminate in the heavy brass end-plates B and C, and an additional tube D is used for conveying the current to the end-plate C. Heavy terminal [illegible] E and F, [illegible] are [illegible] to the ends of the tubes. Although the tubes are solid drawn, it was thought desirable to bore and turn them. The end-plates are made ½ in. thick, and are provided with bosses where they fit on to the main tubes, thus giving the joints a large cross-sectional area, and all the joints are soft soldered. Very good results were obtained with this coil, and the phase error as compared with the Duddell-Mather [illegible]

Two instruments were made up with these coils, one a reflecting type with bi-filar control, and the other a torsion-head instrument. The reflecting instrument was used in this form for some time and gave very satisfactory results. Most of the tests detailed below were carried out on this instrument, the pressure coils being those illustrated in Fig. 13.

The current-carrying capacity of the current coil is limited largely by the carrying capacity of the inner conductor. This conductor may be solid instead of tubular, but with the tubular construction the carrying capacity may be much increased by maintaining a stream of water through the tube. The current element described above will carry a current of about 1,500 amperes for a short time without undue heating, and the torsion-head instrument was always used without water cooling. In the case of the reflecting instrument, however, the movements of the pressure coil are so much magnified that it is found advisable always to have a small stream of water flowing through the inner tube, in order to prevent convection currents of air from causing false deflections of the movable coils.

Mechanical Joints in the Main Coil.

Although the results of the tests showed that instruments constructed as described above are electrically satisfactory, the constructional advantages to be gained by having a joint in the cage were never lost sight of. Experiments in this direction were made more recently and a quite successful joint has been made. From the experience gained in the experiments with the earlier models, a mechanical joint in the cage was to be feared; but, nevertheless, it was decided to make experiments before abandoning the idea. However, to make a satisfactory joint careful machining was necessary, and as all the machine tools in the workshop were fully occupied with other important work, the following method of jointing was tried first :—

The end-plate C, Fig. 8, was unsoldered from the 40 wires forming the outer conductor, and 40 new pieces of wire, each 2 in. long, were soldered into this plate. A new pressure coil (Fig. 14) was slipped over the inner tube, and then each pair of wires was joined by means of short pieces, each 1 in. long, of copper tubing and soldered, as shown in Fig. 9. It was possible to make each of these joints separately without unduly heating any other part of the coil or damaging the pressure coil. On re-testing, there was found to be no phase disturbance in the main coil, so that one method of opening and closing the cage was discovered. The disadvantages were that it was a somewhat tedious operation to open and close the cage, and—owing to the fact that it was not permissible to heat up all the joints together—some of the wires in the outer cage were buckled, due to uneven expansion and contraction.

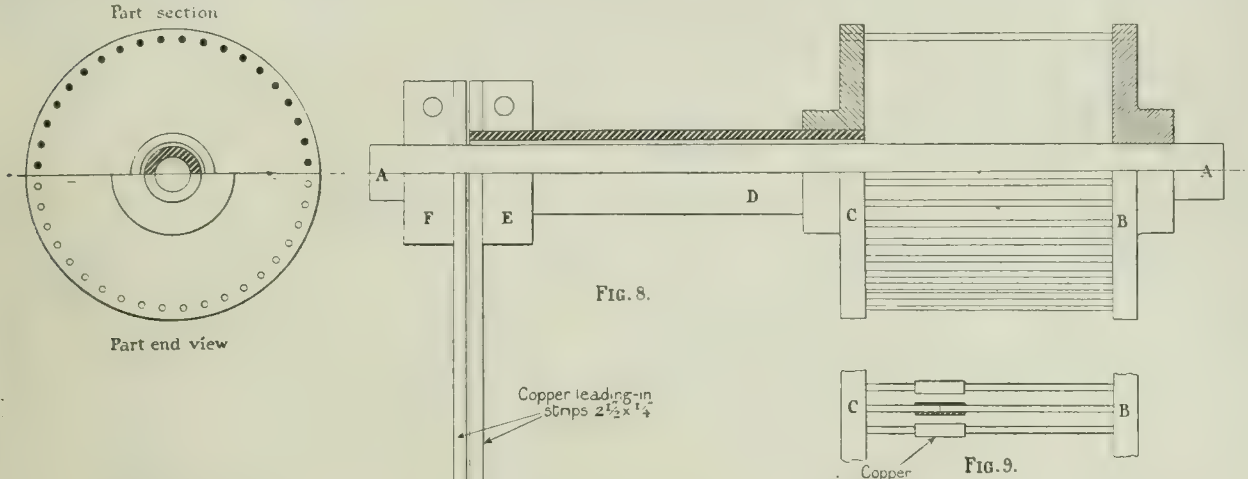


FIG. 8.

FIG. 9.

FIG. 8.—Improved cage form of current element.

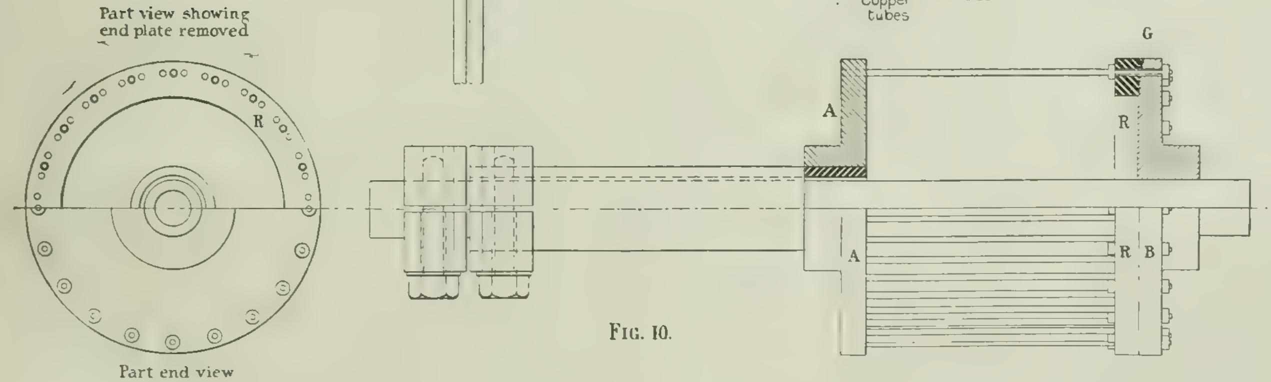


FIG. 10.

FIG. 10.—Mechanical joint in current element.

An [illegible] the [illegible] cage to withdraw [illegible] where the [illegible] melted, and also the heat travelled rather rapidly to the [illegible] ciently to soften the ebonite cheeks on which the coils [illegible] even if successful, was therefore abandoned.

Experiments were next made on the cage with the jointed wires in order to determine what effect was produced on the phase of the main-coil flux when one or [illegible] in Fig. 11, and the pressure coil (Fig. 14) was used. The wattmeter was arranged with the Duddell-Mather instrument as in previous tests, i.e. with pressure coils and main coils in series respectively. First it was verified that both instruments indicated zero simultaneously when the currents in the movable and fixed coils were in quadrature with each other. Conductor No. 8 was then opened and the result was a phase error of 4·8 minutes, the active part of the flux lagging behind the main current. Conductor No. 9 was then also opened and the phase error was increased to 7·5 minutes. This made it obvious that the distribution of the current in the outer conductor is of considerable importance. The two wires 8 and 9 were next re-connected and different combinations of wires opened, and the results of testing for phase errors are set out in Table 2. Referring to Fig. 11, it will be noted that in cases I and VI gaps were made at equal intervals, but in I the gaps were remote from the nominally active sides of the movable coils, while in VI the gaps were made in line with these sides. When gaps are made, however, the circular parts of the movable coils cannot be considered [illegible] quite likely that the magnetic leakage which results when the uniformity of the outer conductor is disturbed causes a redistribution of the current in the inner tube, and also [illegible]

TABLE 2.

	[illegible]		Phase Error
I	Nos.	[illegible]	Nil
II	"	[illegible]	10 minutes. Flux leading current
III	"	20, 21, 30, 31	[illegible] " " lagging
IV	"	30, 31	[illegible]
V	"	[illegible]	[illegible]
VI	"	[illegible]	Somewhat variable, error small and tendency to lagging
VII	"	[illegible]	[illegible]
VIII	"	[illegible]	[illegible]

[illegible]

[illegible] Fig. 12. The 40 wires forming the outer cage are soldered into the end-plate A at one end, and into the brass ring R at the other end. The contiguous faces of the ring and the end-plate B are machined for a true fit, and the end-plate is centred into the ring and fastened to it by means of 20 screws. Satisfactory results were not at first obtained, even when the faces forming the joint were ground together, the phase error amounting to a maximum of 2 or 3 minutes, and varying as the end-plate was turned round in its seating and fastened to the ring in different positions. On close examination it was found that the ends of the copper wires projected very slightly above the surface of the brass ring. This, however, was only evident from the indentations produced in the end-plate B after it had been tightly fastened to the ring. An annular groove G was then turned in the end-plate.

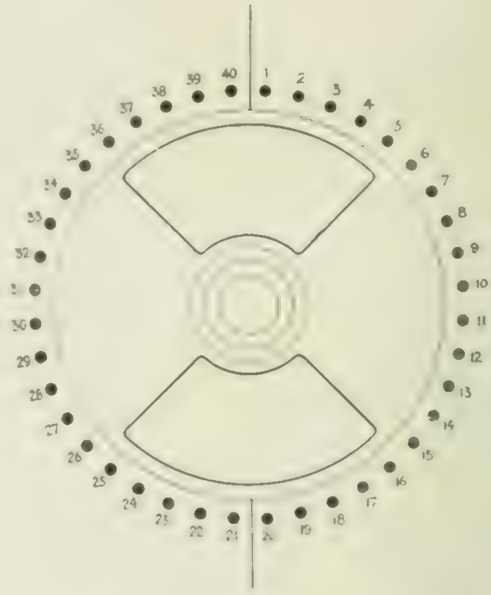


FIG. 11.

On re-testing, a satisfactory result was obtained; and it was found possible to turn the end-plate round in its seating, and to fasten the ring and end-plate together in any position without introducing any phase error. The surfaces forming the joint were always carefully cleaned and covered with paraffin oil before being bolted together.

In a future construction it is intended to make the joint in the middle of the cage, as shown in Fig. 12. This method has several advantages over the method shown in Fig. 10. In the first place it is not necessary to have the pressure coils of a form which can be passed between the wires of the cage or through the ring R. This being so, it follows that the wires forming the outer cage may be spaced closer together, or made in the form of a continuous tube. Thus a "shell" may be substituted for the "cage," and should form a simpler construction. The shell would also form an effective draught screen for the movable coils. The only apparent disadvantage seems to be that the movable coils cannot be inspected unless the main coil be opened.

Pressure Coils for Concentric Wattmeter.

The form of pressure coil used in the wattmeter before it was found permissible to construct the main cage in two separate parts is shown in Fig. 13. It is made up of two coils A and B, wound on flat ebonite bobbins, the length of the bobbins being such as to admit of their being passed between the wires forming the outer cage. The bobbins were joined together by the ebonite strips C and D by means of "Eureka" pins. One of the strips was fixed in position before the coil was put into the cage, and the other was pinned in afterwards. The pieces of ebonite E and F were also secured to the bobbins by means of Eureka pins, and support the Eureka wires G and H which serve for the suspension and the damping vane respectively. Each coil consists of 500 turns of No. 36 S.W.G. silk-covered copper wire, and the coils are connected permanently in series with each other to the ligaments forming the bi-filar control. Full particulars are given in Fig. 13. These coils served for all the tests made on the instrument before the cage was made in two separate parts. The defects in these coils were due largely to its being necessary to build them up within the cage. They are heavy, and not quite so rigid as is desirable for a reflecting instrument.

The second coil, constructed after the cage was made in two parts, is shown in Fig. 14. It consists of four coils formed as shown and mounted on a mica disc. Each coil consists of 50 turns and the four coils are connected in series. This coil was made up completely without the cage and was then slipped between the wires of the outer cage and the inner tube inserted. With the same suspension, the deflection per watt on the instrument was about the same as with the coils shown in Fig. 13, but there is considerable improvement due to the smaller weight, greater rigidity, and smaller self-induction. With regard to rigidity, however, this coil had some defects. The zero of the instrument would sometimes change—about 1/20 to 1/10 in. at a radius of 2 metres—for apparently no reason whatever. The only explanation appears to be that it was due to slight distortion of the mica—which was shellaced—with changes in temperature or humidity of the surrounding atmosphere. The amount of displacement of the zero at a radius of 2 metres would be quite undetectable in a non-reflecting instrument with a pointer 6 in. or 12 in. long. It may be remarked here that a similar displacement of the zero takes place in the Duddell-Mather instrument if the full-load currents are maintained in the coils for a considerable time. The end of the indicating vane deflects about 0·5 mm. to 1 mm., and the author at first attributed this to the expansion of the control spring with increase of temperature. On close investigation, however, it was found that the deflection is in the opposite direction to that which would result from the expansion of

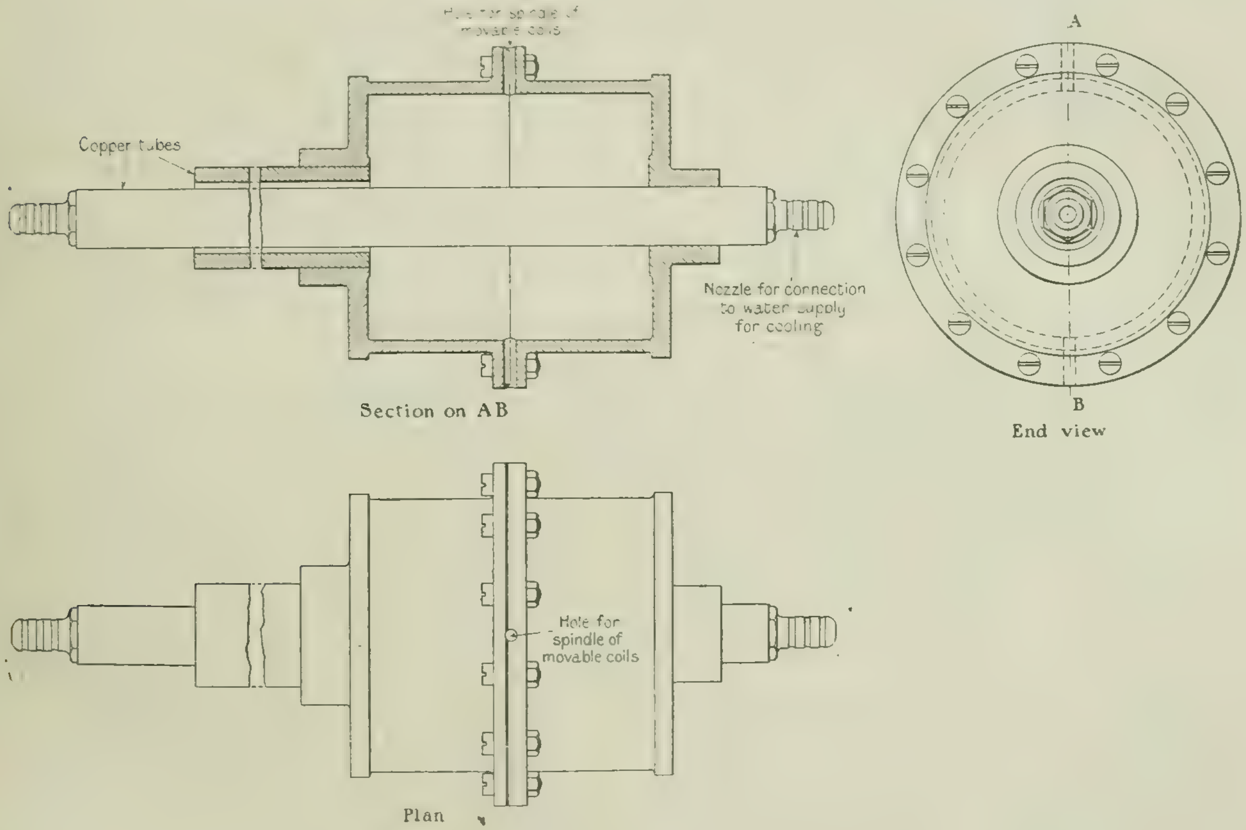


Fig 12.—Current element for concentric dynamometer wattmeter, with outer conductor formed of a shell cast in two halves.

the spring, and it is therefore concluded that it is the result of distortion of the mica sheet on which the movable coils are mounted. No trouble of this kind is noted in another instrument in which the coils are made up as in Fig. 15, in which there is no mica support or other former.

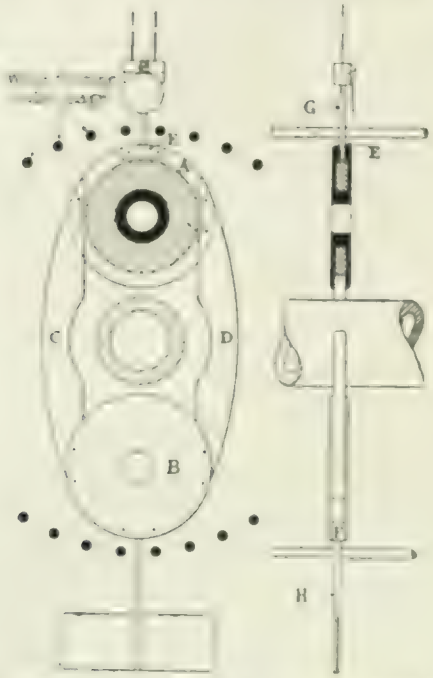


Fig. 14.—Movable system with coils mounted on [illegible] [illegible]

[illegible]

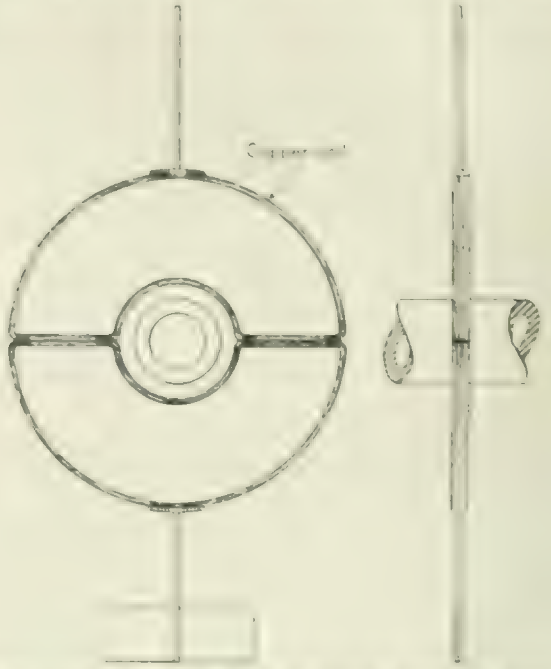


Fig. 15.—Movable system made up without supporting frame: D-shaped coils.

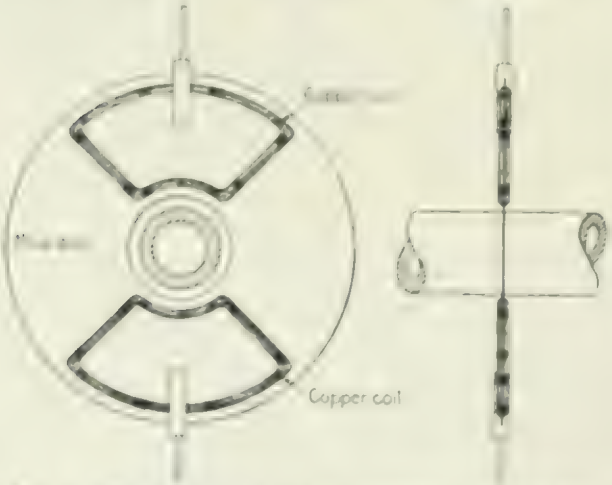


Fig. 16.—Movable system with coils mounted on [illegible]

[illegible]

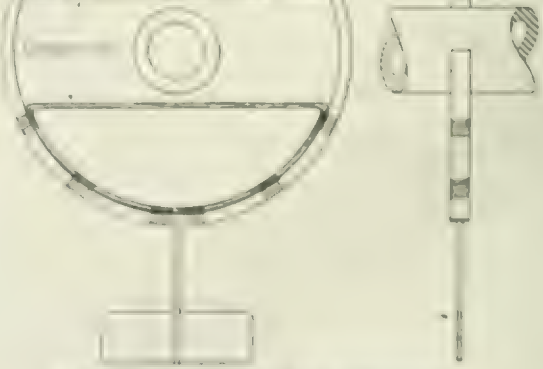


Fig. 17.—D-shaped coils in ebonite ring.

[illegible]

The next form of coil is shown in Fig. [illegible] [illegible] designed [illegible] [illegible] the most [illegible] turns which could be built up within the range. It consists of two D-shaped coils, each of 100 turns, mounted in an ebonite ring. The torque is greater with this coil than with the previous coils, a much more stable zero obtains, and it has been used in the instrument up to the time of writing. The D-shaped coils are probably the best form to use in instruments of the deflectional type, but the construction just described gives too heavy a coil. Experiments are being made with a view to reducing the weight and period of swing, and to substituting air damping in place of the oil damping.

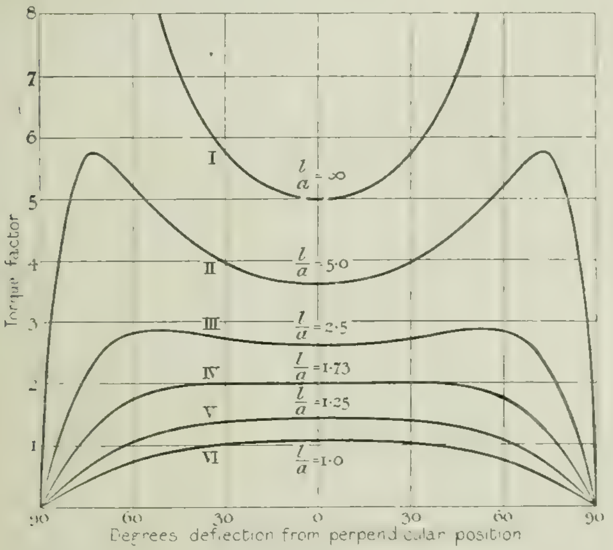


FIG. 17.—Relation between torque factor and deflection for D-shaped coils for different values of the ratio l/a.

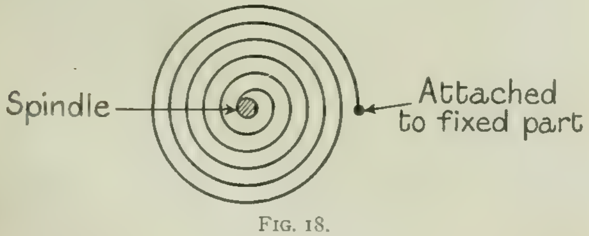


FIG. 18.

TABLE 3.

Relation between Deflection in Degrees and Watts, with Coils shaped as in Figs. 15 *and* 16.

Coils (Fig. 15)			Coils (Fig. 16)				
			Spiral Spring Control			Helical Spring Control	
Watts	Degrees defln.	Degrees Difference per 100 Watts	Watts	Degrees defln.	Degrees Difference per 100 Watts	Degrees defln.	Degrees Difference per 100 Watts
0	25·0		0	0		0·3	
		6·0			6·0		5·7
20	31·0		10	6·0		6·0	
		5·4			6·4		6·0
40	36·4		20	12·4		12·0	
		4·8			6·0		5·7
60	41·2		30	18·4		17·7	
		4·8			5·9		5·8
80	46·0		40	24·3		23·5	
		5·0			6·1		5·7
100	51·0		50	30·4		29·2	
		5·0			6·1		5·5
120	56·0		60	36·5		34·7	
		6·0			6·0		5·6
140	62·0		70	42·5		40·3	
		8·0			6·0		5·7
160	70·0		80	48·5		46·0	
					6·5		5·5
			90	55·0		51·5	
					6·8		5·7
			100	61·8		57·2	
					6·7		5·8
			110	68·5		63·0	
					6·9		6·0
			120	75·4		69·0	
					6·2		6·1
			130	81·6		75·1	
					5·4		6·1
			140	87		81·2	
							6·0
			150			87·2	

(The figures under watts in the table represent values proportional to the watts but not necessarily actual watts. The figures in the difference columns represent the change in the deflection per 100 units of power.)

In an instrument made with a coil of the form shown in Fig. 15 the torque varied very considerably with variation in the angle between the magnetic axes of the main and movable coils. The results are given in Table 3. An investigation into the torque produced in coils varying in shape from that of Fig. 15 to that of Fig. 16, and modifying the dimensions a and l (Fig. 33, Appendix), showed that it is possible to dimension the coils so that the torque is almost independent of the angular relation between the magnetic axes over about 80° to 90° (40° to 45° on either side of the perpendicular position). The curves in Fig. 17 show the relation between the torque factor* and the deflection for different values of the ratio l/a for a constant value of l. Curve No. 1 is for a coil of the form in Fig. 15, l being the length of one active side of the coil, and also for the theoretical case Fig. 16, where a is made zero and the main conductor is assumed indefinitely small in cross-section. It will be noted that the torque-factor is considerably reduced as the ratio l/a is diminished, but when $l = 1·73\,a$, the torque-factor is almost constant over ± 45°. It should be possible therefore to construct a deflectional-type instrument with a practically uniform scale. In order to test this experimentally, a new coil of the form shown in Fig. 16 was constructed, but with the dimensions approximating to $l = 1·73\,a$. For the test the main conductor was formed of a straight copper rod, and the test was made with continuous current. In the first test the movement was suspended by a phosphor-bronze strip which formed one of the connections to the coils, and a spiral spring was used for the second connection and for additional control. A scale of degrees was used to measure the deflection. This arrangement did not give a deflection proportional to the watts, but it was found that the spiral spring moved the position of the axis of rotation of the coil when the coil was deflected. Thus, in Fig. 18, if the rotation of the axis is clockwise, the axis of the coil is moved laterally to the left, while if the rotation is anti-clockwise the axis is moved to the right. It would therefore appear that a spiral-spring control is unsuitable for a suspended type of

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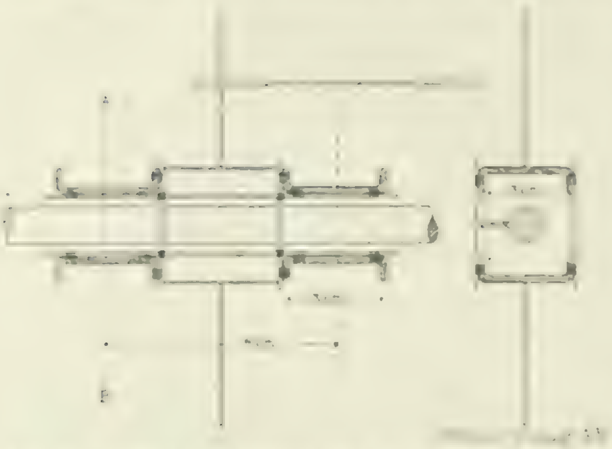
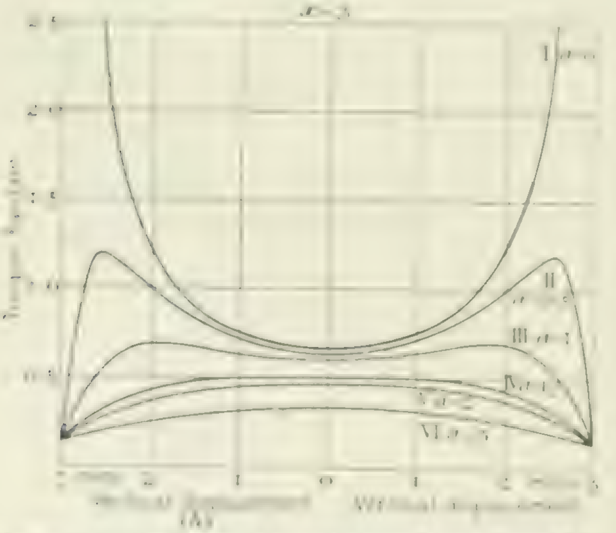
* Appendix.

[illegible] A vertical spring was substituted for the [illegible] spring, and the figures obtained [illegible] are given in Table [illegible]. It will be seen that the deflections obtained [illegible] nearly proportional to the watts. The [illegible]



[illegible]

types of instruments, since a small change in the angular relation between the axes of the main and movable-coil fluxes should not introduce any change in the constant of the instrument.



[illegible]

[illegible]

of the fixed and movable coils, resulting from the deflections due to the currents, or from slight accidental damage to the movement. It will be seen by referring to Fig. 35 and Table † that when the dimensions x = √3 a are chosen, appreciable changes in the position of the movable coils relatively with the main conductor, vertically or laterally, produce only very slight changes in the magnitude of the deflecting force. In an actual experimental test with a movement of the dimensions shown in Fig. 19,* it was found that lowering the coils 5 millimetres from the neutral position, resulted in a change in the force (about a vertical axis) of only 0·8 per cent. In Fig. 20 are curves showing the relation between the torque factor and the displacement *h*, for coils where $x = 3$ cm. † and for different values of *a*. The best result obtains when $x = \sqrt{3}a$. It may be observed that the curves in Fig. 17 are of the same general shape as those in Fig. 20.

Some Comparative Tests made between the Concentric and Duddell-Mather Instruments.

The following results were obtained by comparing the readings on the author's instrument with those on the Duddell-Mather, and, as previously stated, the tests were made on the concentric instrument as constructed before the cage was made in two separate parts.

[illegible] in the main coil.—The main-current coils of the two instruments were connected in series with each other and a suitable resistance, to one generator of the double alternator set,‡ and the pressure coils of the two instruments were also connected in series with each other and a non-inductive resistance to the second generator (Fig 30). The phase of the current in the pressure coils was then adjusted until the reading on the concentric wattmeter was zero, and the readings of the main-coil and pressure-coil currents, and the indication on the Duddell-Mather instrument were noted. These observations were:

Main-coil current 100 amperes.
Pressure-coil current 0·1 ampere.
Resistance of pressure-coil circuit 1,000 ohms.
Watts indicated by concentric instrument 0.
" " Duddell-Mather instrument 2.
Frequency of the current 50 periods.
Total volt-amperes = 100 × 0·1 × 1,000 = 10,000.

If it be assumed that the flux in the main coil of the Duddell-Mather instrument is strictly in phase with the main current, and if θ be the angle between the flux and the current in the concentric instrument, then

$$\sin\theta = \frac{\text{Watts}}{\text{Volt-amperes}}$$

and $$\theta = 0{\cdot}0002 \text{ radian}$$

This is a very small phase error, and the wattmeter would only need correcting if it were used on a very low power factor. For example, if the power factor were 0·1 the correction would be about 0·2 per cent. It may be

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[illegible]

[illegible]

[illegible]

stated here, however, that the cages of the two concentric wattmeters have since been rebuilt, each in two parts, and tests carried out on them in the manner described above indicate that the phases of the fluxes in the concentric and Duddell-Mather instruments are in exact agreement.

In carrying out the test the 10 coils of the Duddell-Mather instrument were connected in parallel, so that the instrument was arranged for a full-load current of 100 amperes. It was thought desirable to determine whether bad contacts at the plugs in the commutator affected the relative phases of the flux and current in the main coils. Several observations were made on the two instruments with one or more of the Duddell-Mather coils open circuited, and also with one or more of the plugs loosened; but under all conditions the two instruments showed the same relative phase difference (0·0002 radian) between the fluxes. This is really a severe test for the Duddell-Mather instrument, and the author concluded therefore that it was safe to rely on the instrument as a standard for the comparison.

Tests at different power factors.—The concentric and the Duddell-Mather instruments were connected up in the usual manner adopted for the comparison of the readings of two wattmeters, and observations were made at power factors of unity, 0·5, 0·3, and 0·17, with leading and lagging currents. The scale used with the concentric instrument is a uniformly divided one, and the deflection is not exactly proportional to the watts; so that in order to avoid errors due to scale calibration, the deflection was maintained at the same value for the three measurements on unity and 0·5 power factor with leading and lagging currents, by varying the main current at the same time as the power factor was varied; i.e. the watts were kept constant but the power factor varied. In the same manner the three observations made at unity and 0·3 power factor were taken at a fixed deflection. The results are given in Table 4, and it will be seen that when corrections are made for the pressure-coil lag the two instruments agree as nearly as they can be read. The ratio of the deflections on the two instruments, as shown in the last column, remains constant and independent of the power factor.

Another series of observations was then taken with the resistances of the pressure-coil circuits increased so that the error due to pressure-coil lag was negligibly small in both cases. The resistance of the Duddell-Mather instrument was made up to 20,000 ohms, and that of the concentric instrument to 40,000 ohms, and comparisons were made down to zero power factor. The results are set out in Table 5.

TABLE 4.

Power Factor	Deflection on Concentric Instrument	Deflection Corrected for Lag in Pressure Coil	Deflection on Duddell-Mather	Deflection Corrected for Lag in Pressure Coil	Ratio Duddell-Mather / Concentric
Unity	280	280	99·6$_5$	99·6$_5$	3,559
0·5 leading current	280	280·7	99·8$_5$	99·9	3,559
0·5 lagging ...	280	279·3	99·5	99·4$_5$	3,561
Unity	145	145	51·8$_5$	51·8$_5$	3·576
0·3 leading current	145	145·6$_5$	52·0	52·0$_5$	3·575
0·3 lagging ...	145	144·3$_5$	51·6	51·5$_5$	3·571
Unity	100	100	35·7	35·7	3·570
0·17 leading current	100	100·9	36·0	36·0$_7$	3,575
0·17 lagging ...	100	99·1	35·4$_5$	35·3$_5$	3·570

The corrections for phase lag in the pressure coils were obtained by means of Fig. 23.

Inductance of pressure coils of concentric wattmeter = 13·6 milli-henries.
Resistance of pressure-coil circuit of concentric wattmeter = 2,950 ohms.

Inductance of pressure coils of Duddell-Mather wattmeter = 5·7 milli-henries.
Resistance of pressure-coil circuit of Duddell-Mather wattmeter = 3,000 ohms.

Frequency of current = 50 periods.

TABLE 5.

Volt-amperes	Power Factor	Reading on Concentric Instrument	Reading on Duddell-Mather
40,000	0·0 current lagging	0·0	0·0
40,000	0·29 ,, ,,	50·0	58·6
17,400	0·67 ,, ,,	50·0	58·6
12,400	0·95 ,, ,,	50·0	58·6
12,600	0·93 ,, leading	50·0	58·6
17,700	0·66 ,, ,,	50·0	58·6$_5$
31,600	0·37 ,, ,,	50·0	58·6$_5$
40,600	0·29 ,, ,,	50·0	58·6$_5$
40,400	0·0 ,, ,,	0·0	0·0

Frequency of current = 50 periods.

At zero power factor the watts indicated by the wattmeter are $\pm V I \sin\theta$, where θ is the phase lag in the pressure-coil circuit. With 20,000 ohms in series with the pressure coil, θ for the Duddell-Mather instrument at 50 periods is 0·00009 radian, and with 40,000 volt-amperes $V I \sin\theta = 3{\cdot}6$ watts. The constant of the in-

[illegible] watts [illegible] on the scale [illegible] due to the [illegible] less than [illegible] mm. and [illegible] the power indicated by the concentric instrument would be 4·4 watts, and the constant of the instrument is approximately 250 watts for 0·1 in. The indication would thus be less than 0·002 in. (0·05 mm.). If the small phase error of 0·0002 radian which was found to exist between the fluxes in the main coils of the two instruments be taken into account, the indication on the concentric instrument would be 0·005 in. (0·12 mm.). The difference in the deflections on the two instruments would therefore be less than 0·05 mm., which is hardly discernible. Under these circumstances both wattmeters ought to indicate zero simultaneously, and actually they did so. Repeated tests on the instruments confirmed that however the power factor was varied the indications of both agreed as nearly as they could be read.

[illegible] OF THE REFLECTING CONCENTRIC INSTRUMENT AS A STANDARD WATTMETER.

The scale at present used with the instrument is a straight one, 43 in. long, divided into tenths of an inch and placed approximately 2 metres away from the instrument. A calibration curve may be used with the wattmeter when desired, but for standard purposes the deflection is, as far as possible, always arranged to be either a fixed value or to deviate from the fixed value by only a small amount. This is brought about by varying the resistance of the pressure-coil circuit until a suitable constant is obtained. By adopting this method of constant deflection the necessity for drawing out a correctly divided scale is avoided, the accuracy of reading is constant, the work entailed in verifying the constant of the instrument is reduced to a minimum, and, in the event of its being necessary to dis-[illegible] constant is readily determined. These are great advantages when experiments are being carried out on the instrument itself.

[illegible] the [illegible] manner: [illegible] non-inductive [illegible] so that the total resistance of the [illegible] ed in the main circuit and is adjusted until the [illegible] flection is obtained on the wattmeter scale. [illegible] Then

[illegible] circuit,

[illegible]

d = [illegible]

[illegible]

That is to say,

Watts indicated by instrument $= k\,r\,d$,

since I^2R is the power absorbed by the resistance R. In fact it will be clear from Fig. 21 that the method of calibration consists in making the wattmeter measure the power absorbed in the resistance R, and the true value of this power is readily calculable if the resistance of R and the value of the current are known. When the instrument is in use after calibration, if the resistance of the pressure-coil circuit be made a multiple of the resistance r, say $n\,r$, the watts indicated by the instrument will be $n(k\,r\,d)$, so that the resistance of r need not be known in ohms. It is most convenient, however, to know the exact resistance of r.

This method of calibrating ensures a minimum of errors. Only one current has to be measured, and in making the measurement, therefore, no assumption is made with reference to the constancy of a second current or pressure. If the resistance r is chosen so that the desired deflection is produced with a potential difference at the terminals of the resistance R about equal to that of a standard cadmium cell (i.e. a current of 1,000 amperes if $R = 0·001$ ohm), certain possible errors in the potentiometer are eliminated. The potentiometer, as such, is in fact quite unnecessary when the above conditions obtain, and the author is arranging the testing circuit as indicated by the dotted lines in Fig. 21. In this case the main current is adjusted until the potential difference on the resistance R exactly balances the electromotive force of the standard cell. The resistance r is then varied until the required deflection is obtained.

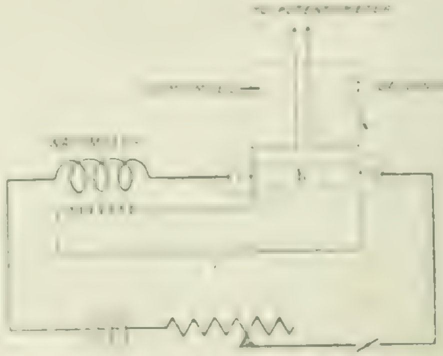

FIG. 21.—[illegible] wattmeter or ammeter.

The accuracy of the calibration will obviously depend upon the accuracy with which the resistances R and r are [illegible] coefficient of resistance of the pressure-coil circuit is [illegible] of resistance of the circuit is less than 0·02 per cent per [illegible] C. The reduction in resistance of the standard [illegible] and r diminished, corrections for this might become necessary.

WATTMETERS FOR HIGH AND LOW POWER FACTOR MEASUREMENTS.

In good dynamometer wattmeters designed to give a full-scale deflection with full-load volts, full-load amperes, and unity power factor, it is generally hardly necessary to make corrections for the phase lag in the pressure coils even when the instrument is used on low power factors. This is shown by the following example :—

Suppose in a wattmeter designed for 100 volts—

inductance of the pressure coil = 10 milli-henries,
resistance of the pressure coil circuit = 5,000 ohms,
full-scale deflection = 100 divisions.

Then, for full-load volt-amperes at a power factor of 0·1,

deflection on the scale = 10 divisions,

percentage error due to the phase lag in the pressure-coil

$$= 100 \times \frac{2\pi f L}{R} \times \tan\phi$$

$$= \frac{100 \times 2 \times 3{\cdot}14 \times 50 \times 0{\cdot}01}{5{,}000} \times 9{\cdot}96 = 0{\cdot}63\ \%$$

But as the deflection is only 10 divisions on the scale, this error is not likely to be greater than the error of observation at the deflection considered.

It must not be assumed, however, that all the instruments so calibrated are free from measurable errors at low power factors. There are, in some types, serious errors due, not to the phase lag in the pressure coil, but to the other disturbances referred to in this paper. In Table 6 are the results of tests made by the author on three different makes of wattmeters designed for currents not exceeding 50 amperes. Wattmeter A is a satisfactory one ; but wattmeters B and C are not. It will be noted that in both B and C the instruments indicate *high* with leading currents, whereas the phase lag in the pressure coil would make them indicate *low* with leading currents. The errors appear to be those due to eddy currents, and it may be stated here that in the instrument C the usually non-inductive resistance is wound inductively, and its inductance is still further increased by threading the bobbin on which the resistance is wound with one or two strands of iron wire. This leads to the assumption that instead of devising a means of compensating the phase lag in the pressure coil, the phase lag is increased to compensate a more serious error in the opposite direction. The workmanship in these (C) instruments is excellent, and they are provided with knife-edge pointers and parallax mirrors ; but they are not good wattmeters. It is obvious that it is worse than useless to correct for the phase lag in the pressure coils of wattmeters B and C, since, as is shown by the table, the corrected errors would be greater than the observed errors.

The requirements in a wattmeter for making accurate measurements at low power factors are much more exacting than those which obtain in the high power factor instrument. In making measurements of the iron and copper losses in large reactance coils, transformers, and induction motors, the power factor often falls as low as 0·05. To obtain accurate results it is essential that a reasonably large deflection be obtained on the wattmeter used, and an instrument is required which will give a full-scale deflection with full-load volt-amperes and a power

TABLE 6.

Wattmeter Tested	Reading on Wattmeter	Power Factor	Error (observed) %	Error due to Pressure-coil Inductance (calculated) %
A. Max. current, 50 amps. Max. pressure, 150 volts. Resistance of pressure-coil circuit, 7,245 ohms. Inductance of pressure-coil, 3·3 milli-henries	2,000	1·0	0·0	
	2,000	0·5 lag	0·0	0·025 high
	2,000	0·25 lag	0·0	0·055 high
	2,000	0·25 lead	0·5 high	0·055 low
	0	0·0 lag		
	0	0·0 lead		
B. Max. current, 50 amps. Max. pressure, 100 volts. Resistance of pressure-coil circuit, 3,000 ohms. Inductance of pressure-coil, 2·7 milli-henries	4,500	1·0	0·0	
	3,000	0·67 lag	1·33 low	0·031 high
	3,000	0·66 lead	0·33 high	0·031 low
	2,000	0·45 lag	2·0 low	0·055 high
	2,000	0·44 lead	1·01 high	0·058 low
	1,500	0·34 lag	2·0 low	0·078 high
	1,500	0·33 lead	2·04 high	0·082 low
C. Max. current, 40 amps. Max. pressure, 160 volts. Resistance of pressure-coil circuit, 8,316 ohms. Inductance of pressure coil, 11 milli-henries. Inductance of pressure-coil circuit, 128 milli-henries	2,000	1·0	0·0	
	2,000	0·5 lag	1·88 low	0·83 high
	2,000	0·25 lag	3·45 low	1·86 high
	2,000	0·25 lead	4·89 high	1·86 low
	143	0·0 lag		
	140	0·0 lead		

The terms *lag* and *lead* in the table refer to the current with respect to the pressure.
The percentage errors have been corrected to be zero at unity power factor.

[illegible] less. To obtain this on low-voltage circuits, and at the same time to maintain a reasonably strong control on the movement, the resistance of the pressure-coil circuit has to be diminished to a value which, in some cases, makes the pressure-coil inductance correction somewhat large at low power factors. It is very important indeed that there should be no phase error in these instruments other than that due to the inductance of the pressure coil.

To correct for the phase lag in the pressure coil a curve like those in Fig. 22 will be found very useful. The percentage correction is approximately $\pm 100 \times \frac{2\pi f L}{R} \tan \phi$. and for a particular instrument, $100 \times 2\pi L$ is a constant, so that a curve may be plotted showing the relation between the power factor ($\cos \phi$) and $100 \times 2\pi L \tan \phi$. Then to obtain the percentage correction at a particular power factor it is only necessary to interpolate the value of $100 \times 2\pi L \tan \phi$, and multiply the value so obtained by

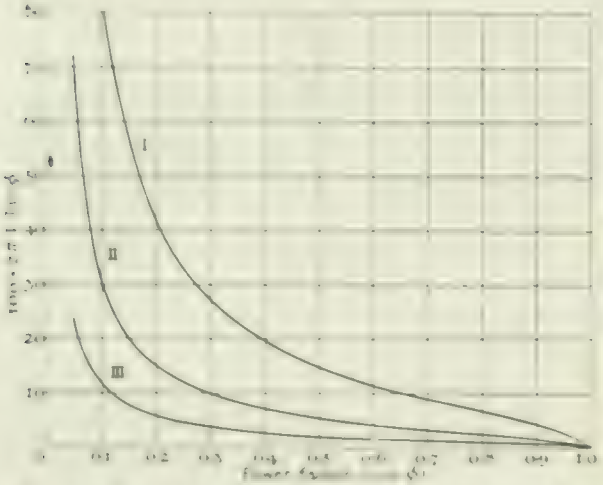

Fig. 22.—Relation between $100 \times 2\pi L \tan \phi$ and $\cos \phi$ for three coils having the following inductances:—

I 13·6 millihenrys.
II 5 ,,
III 1·9 ,,

(frequency ÷ resistance). For example, suppose the power factor of the circuit under test to be 0·1, the frequency 50, and the resistance of the pressure-coil circuit 2,000 ohms. The percentage correction for the coils referred to in Fig. 22 would be:

$$\text{I.} \quad 85 \times \frac{50}{2000} = 2\cdot12 \text{ per cent}$$

$$\text{II.} \quad 31 \times \frac{50}{2000} = 0\cdot78 \text{ per cent}$$

$$\text{III.} \quad 12 \times \frac{50}{2000} = 0\cdot30 \text{ per cent}$$

These figures will illustrate the advantage gained in the concentric instrument by using the pressure coils shown in Fig. [illegible] instead of those shown in Fig. [illegible].

The experiments made on the author's concentric instrument show that it is well suited to the low power factor measurements referred to above. The torsion-head instrument previously mentioned was used for a short time in the Transformer Department of the British Westinghouse Company, for the measurement of copper losses in cases where the current was over 1,400 amperes and the power factor about 0·05, and was found to be quite satisfactory. A unique feature of this torsion-head instrument is that the whole of the fittings outside the main current element are made of metal. This is a distinct constructional advantage obtaining with the concentric system, on account of there being no magnetic field produced outside the cage by the main current.

DOUBLE ELEMENT WATTMETERS FOR TWO-PHASE AND THREE-PHASE POWER MEASUREMENTS.

The author has recently made tests on the concentric instrument with the view to the construction of a two-

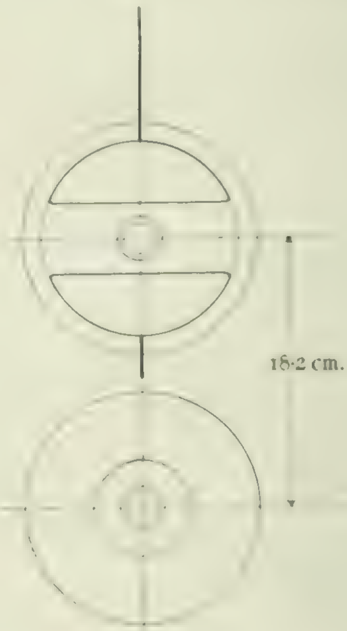

Fig. 23.—Arrangement of two concentric current elements for polyphase wattmeter.

element (polyphase) standard. Dr. Sumpner has pointed out that it is not possible to construct an ordinary deflectional two-element wattmeter without working to a predetermined scale.* But in the zero types of instruments, torsion-head and balance, and also in a deflectional type used at a constant deflection, this defect does not obtain. The defects in two-element dynamometer wattmeters, other than the one referred to, are due to (*a*) magnetic, (*b*) electrostatic, disturbances between the two elements of the meters. Both these defects are eliminated naturally in the concentric system, because (1) the main currents produce no magnetic field outside the main-coil elements, and (2) each element of the movable system is enclosed within a metal cage at the same potential as itself. Although the cages may be at a comparatively high difference of potential from each other, the moving system is effectively screened from electrostatic disturbances.

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* *Journal I.E.E.*, [illegible], vol. [illegible], p. [illegible].

In making the tests, two cages were arranged as in Fig. 23, there being only one movable coil, and this supported within the top cage. A potential difference of 500 volts was applied between the moving coil and its containing cage and a deflection of 11 divisions was obtained on the scale. The moving coil was then connected directly to the cage containing it, and a potential difference of 500 volts was applied between the two cages. No resulting deflection could be detected.

Next, a current of about 0·1 ampere was maintained in the movable coil, and a current of 1,100 amperes in the second cage, the two currents being adjusted to be in phase with each other. The particulars are given below :—

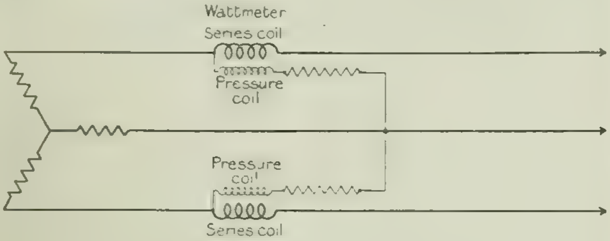

FIG. 24.—Two wattmeter connections for three-phase power measurement.

Distance between the centres of the cages = 18·2 cm.
Voltage on pressure coil = 92 volts.
Current through second cage = 1,100 amperes.
Deflection produced on scale = 7·5 divisions.
Constant for wattmeter = 0·00467 watt per ohm per division.
Resistance of pressure coil = 930 ohms.
Watts indicated by instrument = 32·6.
Watts which would have been indicated if the current and pressure had been applied to the one element = 101,200.

The error introduced is therefore 3·2 parts in 10,000. The interference is thus very small and it is not at present certain whether it is due to magnetic leakage from the current cage, or to stray fields from the main leads connecting to the instrument. There will be bulging of the magnetic field through the wires forming the outer conductor, but the magnetic field due to this at any point without the cage will be exceedingly small provided that there is symmetrical distribution of the main current. Further experiments in this direction will be made later with the main-current element constructed as suggested by Fig. 12. The following considerations will serve to show the advantages of a standard two-element meter for checking the accuracy of three-phase integrating meters tested on a three-phase load :—

Some time ago the author made tests on polyphase integrating meters of various types, and the tests showed that when the meters were tested on a three-phase load the results were different from those obtained when the meters were tested on a single-phase load.* One of the chief reasons for this is that there is interference between the different single-phase elements, of which there may be two or three in a particular meter. When the three-phase testing circuit is properly arranged, it is less tedious to test a three-phase meter with a three-phase load than to test each element separately on a single-phase load, especially if a three-phase standard is available. At the same time, if there were no interference whatever between the single-phase elements of the meter, a properly carried out single-phase test would give exactly the same results as obtain on the three-phase test. If this were not true, then it would not be possible to construct a two-element, three-phase standard and calibrate it with continuous current. The author believes that it is possible to construct such a standard with the concentric system.

When two single-phase indicating standards are used to check a polyphase integrating meter, it is usual to keep the indication on one of the indicating instruments constant by hand regulation of the load. But if the load on only one of the wattmeters is observed, it is by no means quite certain that the constancy of this part of the load is representative of the constancy of the total load. For, if the wattmeter reading should rise, the load is reduced by hand; but the rise may be due to a small variation in the power factor, and if so, the reading on the second wattmeter may have fallen. So that reducing the load on wattmeter No. 1 will result in reducing the load on wattmeter No. 2 still further, and consequently in reducing the total load below the requisite value. The elimination of this possibility is one of the several advantages gained by using a polyphase standard.

SCHEME OF CONNECTIONS FOR TESTING TWO-ELEMENT POLYPHASE METERS BY THE TWO-CIRCUIT OR FALSE LOAD METHOD.

Fig. 24 shows the ordinary method of connecting two wattmeters, or one polyphase wattmeter for measuring the power in a three-phase circuit. If these wattmeters are connected in the same manner on a two-circuit three-phase load (Fig. 25), one of the common point connections, A or B, must be disconnected or the result will be that the high-pressure volt supply will be connected directly in parallel with the low-pressure current supply, and a partial short-circuit will result. On the other hand, if the connection A be eliminated, then the current and pressure coils of wattmeter A will have practically the full difference of potential of the volt supply

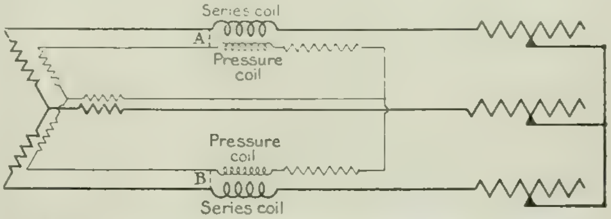

FIG. 25.—Two-supply, three-phase testing circuit to represent conditions in Fig. 24. Common point connections A and B cannot both be made at once.

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* *Journal I.E.E.*, 1911, vol. 47, p. 54.

[illegible] [illegible] with consequent liability to error and damage. The method of getting over this difficulty adopted by the author is to make the connections as in Fig. 26. Only one pair of wattmeters is shown, but any number of pairs may be compared by connecting their current coils in series and their pressure coils in parallel in the respective circuits. If the wattmeter under test is a polyphase instrument of the dynamometer type, any errors there may be in the instrument due to electrostatic disturbance between the elements will not show up in the test. The instrument should therefore be subjected to an additional test, made by connecting each pressure coil to its respective main coil and then applying the full stated pressure between the two elements. Any resultant deflection of the pointer is probably due to electrostatic disturbance between the two elements.

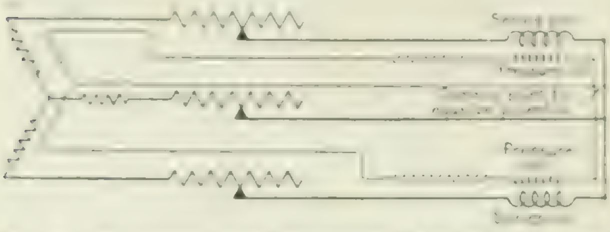


FIG. 26.—Modification of the connections in Fig. 25 to eliminate electrostatic disturbances in the wattmeters.

USE OF CONCENTRIC REFLECTING WATTMETER AS A STANDARD ALTERNATING-CURRENT AMMETER.

When the wattmeter is connected up for calibration as described on page 391 it becomes a shunted-type dynamometer ammeter and can be used as such. In order that the continuous-current calibration may be suitable for alternating current, then, the shunt must have the same time-constant as the movable-coil circuit, or both time-constants must be reduced to such a small value that the frequency error is negligibly small. When the instrument is arranged as an ammeter, however, much wider limits of phase displacement are allowable than is the case when it is arranged as a wattmeter because the instrument is measuring on practically unity power factor. If a 0·001-ohm shunt of the Paterson and Rayner type be used with the reflecting instrument as at present arranged, and the resistance of the movable-coil circuit be made 100 ohms, the inductance error at 100 periods is less than 1 part in 10,000. With this arrangement the instrument will give a deflection of approximately 250 scale divisions (25 in.) for 300 amperes, and the range may be increased up to the full-load carrying capacity of the shunt or the dynamometer by increasing the resistance of the movable-coil circuit. With a 0·01-ohm shunt the minimum current for a full-scale deflection is about 100 amperes. Above the minimum current the deflection may always be maintained at a constant value by varying the resistance of the movable-coil circuit. The current in amperes is given by

$$\sqrt{\left(\frac{k\,a}{R}\right)}$$

the letters in the formula having the same designation as on page 392.

CONCENTRIC NON-INDUCTIVE STANDARD RESISTANCES.

The author suggests the following as a method of constructing non-inductive standards of low resistances. The method is the natural development of working with the concentric wattmeter.

If a cylinder of resistance alloy be substituted for the wires forming the outer conductor of the wattmeter cage as in Fig. 27, a non-inductive, low-resistance tube is obtained. If the thickness of the resistance alloy were indefinitely small the inductance of the tube would be zero whatever the length of the tube. For finite thicknesses of the material the inductance is calculable and may be made very small. For example, suppose the resistance alloy to be manganin of the following dimensions:

Length between A and B = 10 cm.
Inside diameter of manganin tube = 13·4 cm.
Thickness of manganin = 0·1 cm.

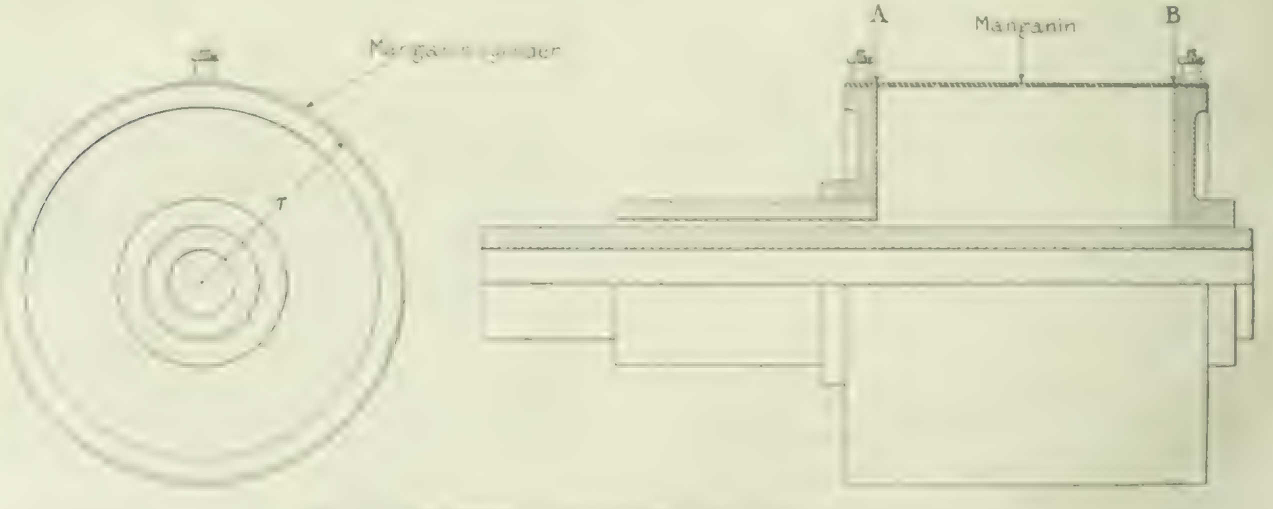


FIG. 27.—Construction of non-inductive, low-resistance standards.

The resistance between A and B of this tube would be approximately 0·0001 ohm. The magnetic flux density on the inside surface of the tube is $2\,I/r$, and on the outside surface zero. If the flux density in the material be taken as one-half of that on the inside surface, the total flux cutting the material with a current of one C.G.S. unit is:

$$\frac{1}{r} \times \text{thickness} \times \text{length}.$$

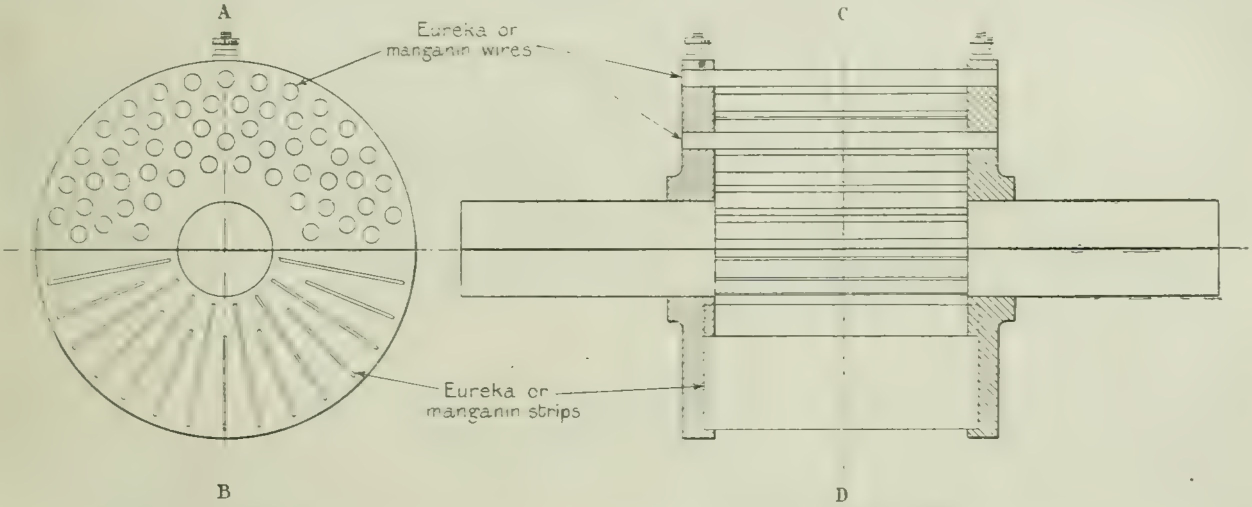
$$= \frac{1}{6\cdot7} \times \frac{1}{10} \times 10 = 0\cdot149 \text{ C.G.S. line.}$$

The inductance is thus 0·149 cm., and the time-constant is $1\cdot49 \times 10^{-7}$.

For the dimensions:

Length between A and B = 20 cm.
Inside diameter of manganin tube = 5·4 cm.
Thickness of manganin = 0·05 cm.
Resistance is approximately 0·001 ohm.
Inductance 0·37 cm.
Time-constant $3\cdot7 \times 10^{-7}$.

The effective inductance and time-constant of this latter resistance are rather more than one-tenth of the inductance and time-constant given by Paterson and Rayner for their 0·001-ohm water-tube type with the special sheath.*



Section through CD

Section through AB

FIG. 28.—Circular shunt for continuous current, showing alternative construction for wires or strips of resistance alloy.

The form of the resistance suggested above differs from that of the concentric resistances recently designed by Dr. Drysdale † in that in the present form the inner conductor does not form part of the resistance, and the non-inductiveness does not depend upon getting the inner and outer tubes close together.

An evenly distributed entry of the current into the resistance material is essential in standard resistances, and particularly so in non-inductive types, and the arrangement of the concentric connections shown in Fig. 27 appears to be the most effective way of ensuring this.

Ammeter shunts.—The circular arrangement of the resistances would appear to be suitable for the construction of ordinary heavy-current shunts for continuous currents where a high degree of accuracy is desirable. It is fairly well known, among those interested, that it is a difficult matter with shunts of the ordinary rectangular type to obtain uniform distribution of the current over the whole of the resistance strips or wires, especially with any variation in the arrangement of the connection to the main cables. A shunt constructed as in Fig. 28 should effectively remedy this, and while possibly it would be more expensive to construct than the usual rectangular pattern, it would be more satisfactory where the meter used in conjunction with it is intended for important measurements, such as is the case with watt-hour meters of the shunted type, and with ammeters used for testing large continuous-current generators. It should be noted that a shunt constructed as in Fig. 28 is not a non-inductive one.

THE METHOD OF MEASURING SMALL DIFFERENCES OF PHASE.

The method of measuring the phase difference between the magnetic flux and the current which produces it, and between any two currents which are nearly in phase with each other, was referred to by the author briefly in the *Journal I.E.E.*, 1913, vol. 51, page 346.

Suppose it is desired to measure the phase difference between the primary and secondary currents of an instrument series transformer. If the primary current be passed through the fixed coil, and the secondary current through the movable coil of a dynamometer free from phase errors, the dynamometer reading is

$$k\,I_f\,I_m \cos\phi,$$

where I_f and I_m are the currents through the fixed and movable coils respectively of the dynamometer, k is a constant determined with, say, continuous current, and ϕ is the angle of phase difference between the two currents.

It is shown by Dr. Sumpner,† however, that if ϕ is a

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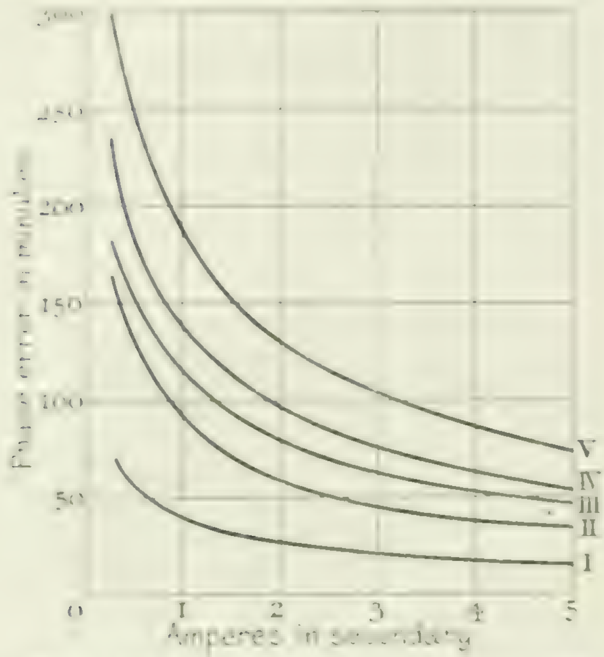
* *Journal I.E.E.*, 1909, vol. 42, p. 494.
† *Electrician*, vol. 77, p. 629.

* *Philosophical Magazine*, 1905, p. 155.

[illegible] differ in form, the product of their R.M.S. values would



[illegible] ndary load of 15 volt amperes at 50 [illegible]

[illegible] two currents are in phase, i.e. when the dynamo- [illegible]

[illegible]

is therefore unsuited to the measurement of the phase differences in these cases.

A modification of the method is to compare the phases of the two currents with that of a third current of the same frequency, the third current differing in phase considerably from the phases of the two currents to be compared. This may be done by using two suitable dynamometers (or wattmeters), passing the third current through, say, the two movable coils connected in series with each other, the primary current through the fixed coil of one, and the secondary current through the fixed coil of the other dynamometer (Fig. 31). The two dynamometers then read as follows :—

$$\text{I.}\quad k_1 I_p I_m \cos\phi_1$$

and

$$\text{II.}\quad k_2 I_s I_m \cos\phi_2$$

where ϕ_1 and ϕ_2 are the phase differences between the current through the movable coils and the primary and secondary currents (I_p and I_s) respectively of the transformer.

Since I_m is the same current in both dynamometers, $(\phi_1 - \phi_2)$ is the phase difference between I_p and I_s, i.e. between the primary and secondary currents of the transformer.

[illegible] $= \theta$

Then, reading on dynamometer $\text{I} = k_1 I_p I_m \cos\phi_1$

and $\text{II} = k_2 I_s I_m \cos(\phi_1 \pm \theta)$

If it be assumed that $k_1 = k_2$, and that $I_p = I_s$, then if ϕ_1 be 0 and θ is small (not exceeding 3°), $d_1 = d_2$ to within 14 parts in 10,000. But if ϕ_1 be an appreciable angle, $\cos(\phi_1 \pm \theta)$ may be appreciably different from $\cos\phi_1$, and [illegible]

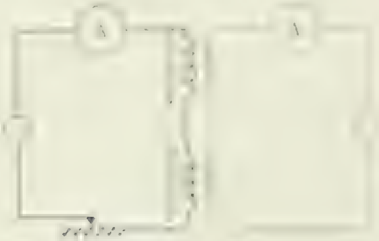
If the phase of the current I_m can be altered by very fine adjustment until $d_1 = 0$, then

[illegible]

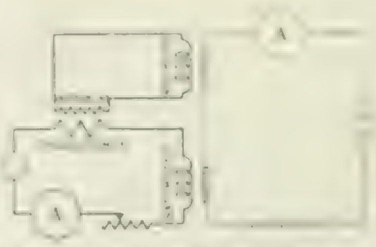
and

[illegible]

For small angles sin θ is the radian measure of θ, and hence the reading of d_2 is directly proportional to θ.



[illegible] dynamometer wattmeter.



[illegible]

[illegible]

[illegible] arranged on the motor-alternator set installed at the School [illegible] may be obtained from the small machine provided with

[illegible]

the movable stator, and the current through the primary winding of the transformer under test from the larger machine. The movable stator is then adjusted until one of the dynamometers indicates zero. Then, if d_1 is made zero—

$$d_2 = k_2 I_s I_m \sin\theta,$$

and if d_2 is made zero—

$$d_1 = k_1 I_p I_m \sin\theta,$$

and θ is calculable if the other factors are known. Or alternatively if d_1 be adjusted to zero, d_2 may afterwards be adjusted to zero by turning the movable stator through θ electrical degrees; and if the angular displacement of the stator can be measured accurately, θ can be determined and the observation is independent (theoretically) of the magnitudes of k_1, k_2, I_p, I_s, and I_m.

The method is employed for the tests previously referred to in this paper, in order to determine whether the active part of the flux in the current coil of a dynamometer wattmeter (that part of the flux which acts directly on the pressure coil) is in phase with the main current. It is essential, however, that an instrument in which this is known to be the case is available for comparison. The two wattmeters are connected up as shown in Fig. 30 with their current coils in series with each other to one machine, and their pressure coils in series with each other to the second machine, and the phase difference between the currents is adjusted until one of the wattmeters indicates zero. If the fluxes in the instrument coils are strictly in phase with the respective currents in both wattmeters, then on adjustment both wattmeters will indicate zero simultaneously. If, however, the two wattmeters do not indicate zero simultaneously, then the instrument which is not known to be free from phase disturbance will have a phase error θ such that—

$$\sin\theta = \frac{d}{k I_f I_m},$$

where d and k are the deflection and constant of the instrument whose indication is not zero, and I_f and I_m are the currents through the fixed and movable coils respectively of the instruments.

In measuring the phase difference between the primary and secondary currents of a transformer, the author has found good agreement between the results calculated from the wattmeter readings and those calculated from the measured displacement of the movable stator. But good agreement is not obtained with the two methods when measuring the phase error in a wattmeter in which there are eddy currents. Also, in the case of such a wattmeter the value of the phase error θ is found to be different when determined with the main-coil current leading relatively to the pressure-coil current, from what it is when the main-coil current is lagging relatively to the pressure-coil current. For example, in a certain wattmeter in which eddy currents are known to be present, the phase error is determined as 23 minutes when the main-coil current is leading, and 32 minutes when it is lagging. The cause of this is somewhat obscure; it may be due to distortion of the wave-shape of the flux by the eddy currents.

In cases where the phase errors are calculated from the wattmeter readings, and not from the measurement of the angle through which the movable stator is turned, the following method of finally adjusting the phase may be used. It is known that when an alternator is loaded the terminal potential difference lags behind the electromotive force. So that if a finely adjustable rheostat be connected to the terminals of the variable-phase machine, the phase of its terminal potential difference may be varied over a moderate range, and thus the final adjustment made at the test bench. The author has found this method particularly useful as the phase shifter is not operated by remote control, and the services of an assistant are not always available. The method should also prove useful where the phase shifter does not admit of infinitely fine adjustment.

The author desires to express his acknowledgments to the Principal and Governing Body of the Manchester School of Technology. He is also indebted to Professor Miles Walker and Mr. M. B. Field for valuable help and suggestions during the progress of the work.

APPENDIX.

CALCULATIONS OF TORQUE WITH DIFFERENT SHAPES OF PRESSURE COILS.

(1) *Double* D-*shaped Coils.*

(A) Coils arranged as in Fig. 15.

Referring to Fig. 32, if the curved parts of the D coils form circles concentric with the main conductor, the forces exerting a turning moment about the axis O are confined to the straight portions l of the coils.

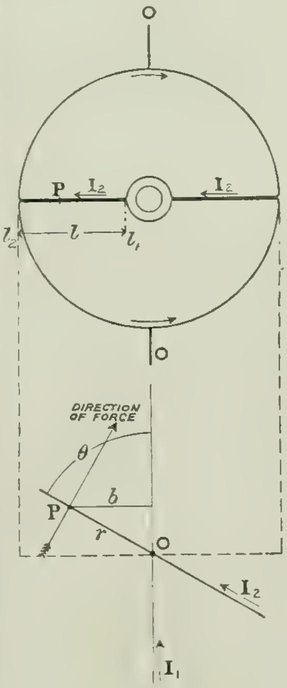


FIG. 32.

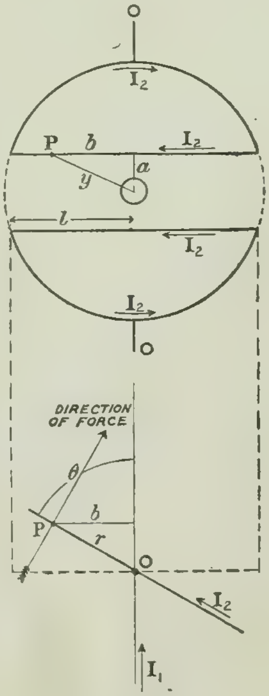


FIG. 33.

[illegible] vertical.

[illegible] the current in the main conductor.

I_1 be the current in C.G.S. units in the main conductor.

I_2 be the total current (current × number of conductors) in C.G.S. units, in the sides l of the movable coil.

l be the length of one active side of the movable coil.

θ be the angle which the side l makes with the main conductor.

Then the force on an element $d\,r$ at the point P (in the direction of the arrow)

$$= [illegible] \text{ dynes}$$

$$[illegible]$$

$$\therefore [illegible]$$

The torque about the axis O due to this force is

$$\frac{2\,I_1\,I_2\,d\,r}{[illegible]}\,[illegible]$$

and total torque on two sides l

$$= [illegible]$$

$$= [illegible] = 4\,I_1\,I_2\,[illegible]$$

The part $4\,I_1\,I_2$ of the expression is similar for all shapes of coils, and the part $l/\sin\theta$ may be termed the "torque [illegible]

[illegible] Fig. 17, is obtained, and it will be obvious that the torque [illegible] This is the best position for the coil if used in a zero-type instrument, since it is the position in which the torque [illegible] least rapidly with changes in the angle θ.

[illegible] of this shape of coil, especially for deflectional instruments, is due to the rapidity with which the torque factor changes with changes in the angle θ.

[illegible]

[illegible]

$$[illegible]$$

$$[illegible]$$

$$[illegible]$$

[illegible]

$$[illegible]$$

$$[illegible]$$

Now a = constant and [illegible] $= r\sin\theta$.

$$\therefore \text{Torque at } P = 2\,I_1\,I_2\,\frac{\sin\theta\,r\,d\,r}{a^2 + r^2\sin^2\theta}$$

and total torque on 4 sides l

$$= 4 \times 2\,I_1\,I_2\sin\theta\int \frac{r\,d\,r}{a^2 + r^2\sin^2\theta}$$

$$= 8\,I_1\,I_2\left(\frac{l}{\sin\theta} - \frac{a\tan^{-1}\frac{l\sin\theta}{a}}{\sin^2\theta}\right)$$

and the torque factor is

$$\left(\frac{l}{\sin\theta} - \frac{a\tan^{-1}\frac{l\sin\theta}{a}}{\sin^2\theta}\right)$$

It will be seen that the first part of this expression is the same as that obtained in case (A) above. The effect of changing the shape of the coils from that of case (A) to that of case (B) is obviously to diminish the torque by an amount represented by $\left(a\tan^{-1}\frac{l\sin\theta}{a}\right)/\sin^2\theta$.

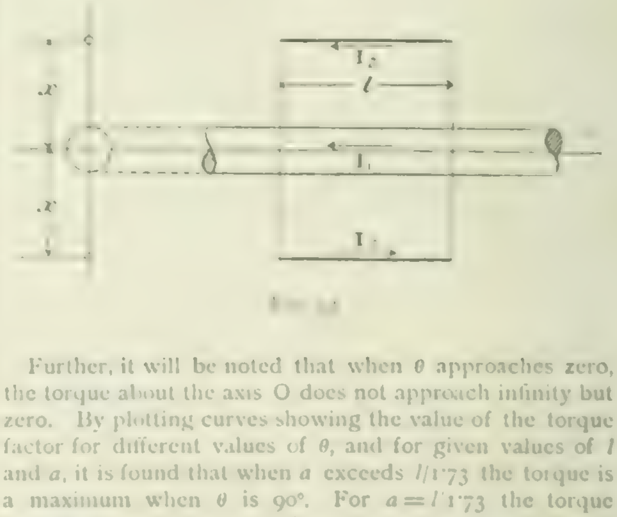


Fig. 34

Further, it will be noted that when θ approaches zero, the torque about the axis O does not approach infinity but zero. By plotting curves showing the value of the torque factor for different values of θ, and for given values of l and a, it is found that when a exceeds $l/1{\cdot}73$ the torque is a maximum when θ is 90°. For $a = l/1{\cdot}73$ the torque factor is nearly constant from $\theta = 45°$ to $\theta = 135°$, and this is usually the best condition for a deflectional instrument. [illegible] have a dent in them.

(2) *Balance-type coils.*—The following treatment of this [illegible] results in constancy of force over a considerable range of movement, was communicated to the author by Mr. M. B. [illegible]

(C) Coils arranged as in the earlier form of Kelvin kilowatt balance, i.e. with the active sides of the movable [illegible]

Referring to Fig. 34, and using the same notation as in [illegible] movable coils, if it be symmetrical about the main conductor

$$[illegible]$$

If the coil be displaced vertically a distance h, the total vertical force on the coil, assuming h is less than x, is

$$2\,I_1 I_2 l \left\{ \frac{1}{x-h} + \frac{1}{x+h} \right\}$$

and the torque factor may be taken as

$$\left(\frac{1}{x-h} + \frac{1}{x+h} \right)$$

Curve No. 1, Fig. 20, shows the relation between the torque factor and the displacement h, when $x = 1{\cdot}73$ cm.

It will be seen that the torque factor varies in a manner similar to that in the case of the D-shaped coils, Fig. 15. The torque is a minimum in the symmetrical position, and approaches infinity as the value of h is made equal to that of x.

(D) Coils arranged as in Fig. 19.

In this case, referring to Fig. 35, the force on the one limb at m is along the radius r and is

$$\frac{2\,I_1 I_2 l}{r},$$

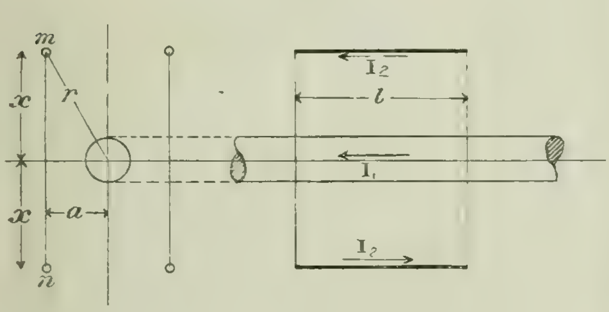


FIG. 35.

and the vertical component of the force is

$$\frac{2\,I_1 I_2 l}{r} \cdot \frac{x}{r} = \frac{2\,I_1 I_2 l\,x}{r^2} = \frac{2\,I_1 I_2 l\,x}{a^2 + x^2}.$$

If the coil is in the symmetrical position in respect of the horizontal axis, as shown, the vertical component of the force for the pair of coils is

$$2 \times 2\,I_1 I_2 l \left\{ \frac{x}{a^2 + x^2} + \frac{x}{a^2 + x^2} \right\} = 4\,I_1 I_2 l\,\frac{2x}{a^2 + x^2}.$$

If the coil is moved vertically through a distance h, the force is

$$4\,I_1 I_2 l \left\{ \frac{x+h}{a^2 + (x+h)^2} + \frac{x-h}{a^2 + (x-h)^2} \right\}$$

assuming that h is less than x; and the part of the expression within the brackets may be termed the torque factor.

If $a = 0$, the condition is the same as in (C) above, and Curve No. 1 is obtained, the vertical force being a minimum with the coil in the symmetrical position.

If $a = x$, i.e. $m\,n$ subtend an angle of 90° at the centre of the main conductor, Curve No. 6 is obtained, the vertical force being a maximum when the coils are in the symmetrical position, $h = 0$.

But if a is less than $x/\sqrt{3}$ a curve with a dent in its crest is obtained.

If $a > x/\sqrt{3}$ the curve is like

If $a < x/\sqrt{3}$ the curve is like

In the latter case there is obviously a value of $\pm h$ giving the same value of force as in the symmetrical position. If this value be h_1, it is represented by the condition

$$\frac{2x}{a^2 + x^2} = \frac{x + h_1}{a^2 + (x + h_1)^2} + \frac{x - h_1}{a^2 + (x - h_1)^2}$$

which simplifies into

$$x^2 - 3\,a^2 - h_1^2 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For given values of x and a this gives the value of h_1 (vertical displacement) at which the force is the same as in the symmetrical position.

By putting $h_1 = 0$, the condition separating the undented from the dented curves is obtained; because if $x^2 < 3\,a^2$ there is no value of h_1 where the force is the same as in the mid position; or there is no real value of h_1 satisfying Equation (1). But if $x^2 > 3\,a^2$ there is such a value for h_1.

TABLE 7.

Relative values of the vertical force with variations in the displacement (h) for balance-type coils,

*when $x = 3$ cm. and $a = 1{\cdot}7$ cm.**

Vertical Displacement (h)	Relative Value of Vertical Force
0	504,625
2 mm.	504,668
4 mm.	504,724
6 mm.	504,586
Lateral Displacement	
2 mm.	504,573
4 mm.	504,350
Lateral and Vertical Displacements	
3·5 mm. 3·5 mm.	504,833

As a comparison with the above figures it may be noted that the relative value of the vertical force in the mid position when

$a = 0$ and $h = 0$ is 666,667

and when $a = 0$ and $h = 2$ mm. 669,640.

For the values* $x = 3$ cm., $a = 1{\cdot}7$ cm., $h_1 = 0{\cdot}575$ cm. In other words, at a distance of 5·57 mm. on either side of the mid position the vertical force is the same as at the mid position. The forces in intermediate positions may be calculated from the expression

$$\frac{3 + h}{1{\cdot}7^2 + (3 + h)^2} + \frac{3 - h}{1{\cdot}7^2 + (3 - h)^2}$$

---

* These dimensions represent a system suitable for a 2,500-ampere balance.

[illegible] is sensibly constant over a [illegible]

[illegible] and for the lateral and vertical displacements, it is necessary to consider the vertical forces on both the coils situate at one end of the moving system, as shown in Fig. 35. It will be seen by the figures in Table 7 that the system is not sensitive to an accidental small vertical, or lateral, or vertical and lateral displacement of the movable coils. They also show that the force on a coil of cross-section 3 mm. × 3 mm. is practically the same as in the theoretical case where the cross-section of the movable coils is assumed indefinitely small. Fig. 20 is a family of curves for $x = 3$, and different values of a and h.

DISCUSSION ON

"VOLTAGE REGULATION OF ROTARY CONVERTERS."*

Manchester Local Section, 13 March, 1917.

[illegible] Mr. [illegible] less current on the consumer's account. This is quite correct because the consumer's account is governed not by the wattless current in the converter but by the power factor on the high-tension side of the transformer, which [illegible]ent. This will be clearly appre[illegible] has not been lost sight of, but I think it is only fair to state [illegible] power companies give lower rates to consumers who take current at a leading power factor, which fact is not mentioned by Dr. Cramp. I think the question of the basis upon which current is charged for is of very [illegible]ated in speci[illegible] manufacturer to offer plant [illegible]rrent is, I think, too strongly [illegible] this increase would only amount to 0·18 per [illegible]e total output, assuming the wattless current to [illegible] with no wattless current. The comparison made between [illegible] I have worked out a case for the range given, and the following are the values of power factors obtained :— Mr. Juhlin.

440 volts.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Power factor on h.t. side of transformer	[illegible]	[illegible]	[illegible]	[illegible]	Lagging

480 volts.

Ditto	[illegible]	[illegible]	0·92	0·95	Leading

The wattless current was fixed so as to give 0·95 leading power factor at the high voltage. It should be pointed out that it is very undesirable to have such a low leading power factor on a converter with the voltage range specified and obtained by reactance control, owing to the large wattless currents required. I think there must be some mistake in connection with the power factors given for the motor converter if they refer to the high-tension side. If the figures given refer to the low-tension side they are of course of no interest except from the point of view of the designer. It does not seem correct to select a set of guarantees for each type and from these draw the conclusion that one type is superior to the other, as when there are several makers of one type it does not follow that the guarantees given by one maker are the best that can be obtained. The following values for the power factor may be obtained without excessive wattless currents, and, as will be seen, these are [illegible]

440 volts.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Power factor on h.t. side of transformer	[illegible]	[illegible]	[illegible]	[illegible]	Lagging

[illegible]

Ditto	[illegible]	[illegible]	[illegible]	[illegible]	Leading

---

* [illegible]

Mr. Juhlin.

It should not be overlooked that as the normal voltage is 460, the set would run most of the time at this voltage, in which case the power factor would deviate very little from unity at any load. Regarding the question what is meant by leading or lagging current, I think it is clear that, when leading currents are referred to as correcting the power factor, they must be leading with respect to the system. The statement that the continuous-current booster has the merit of not interfering with the commutation is contrary to the facts.

The question raised by Mr. Townend of voltage regulation of converters running inverted is mentioned in the paper although not dealt with fully. The conditions obtaining for reactance with the inverted machine are, as stated by Mr. Townend, the same as for the direct-running one. It should be noted, however, that an increase in voltage is obtained by reducing the excitation when running inverted; whereas, with the machine converting alternating current to continuous current the excitation must be increased to obtain an increase in the electromotive force.

I fully agree with Professor Walker that criticism is very useful, provided it is constructive criticism. Referring to the use of the term "reactance" to which he takes exception, I believe I am in good company in this respect, and it appears to me perfectly justifiable to use a term which is well understood by all electrical engineers. The diagrams shown in Fig. 1 are simply typical and intend to show the relations between the different electromotive forces with varying conditions of power factor. I cannot agree with Professor Walker that E_T is constant under practical conditions, as it is unfortunately only too common to find specifications calling for machines to run on a system having as much as 10 per cent variation in the alternating voltage. I think the description in Fig. 7 states exactly what the curves show, as they are intended to give the wattless current at varying load. All the conditions as to per cent regulation, reactance, and resistance, are given, and if the full description is considered I think the curves are clear. I have, however, made an addition stating that the curves refer to the limiting voltages of the range, although this should be clear by considering Figs. 6 and 7. I do not consider the description suggested by Professor Walker for Fig. 7 would make the diagram any clearer. I am of the opinion that it would lead to confusion to say that the curves are applicable whether the converter is shunt or series wound, as it would be necessary to alter the series excitation independently of the load for this to be true, and while this is theoretically possible it is not used practically. I do not think it is quite correct to say that there is no gain by using saturated reactance except when the voltage is reduced. The wattless currents are reduced at light loads when saturated reactive iron is employed whether the electromotive force is increased or decreased, and this may under certain conditions be advantageous. The danger of a sudden drop in the load when the load is being taken off a machine exists, but this is easily guarded against by making the field rheostat finely graded. Referring to the expression for tan ψ_1, it is after all a matter of opinion which form is the most satisfactory. I agree that every effort should be made to present papers in the best form, but the fact that the engineer engaged in practical work does not always view technical questions from the same standpoint as the teacher, should not be lost sight of.

Mr. Ellis's remarks as to the amount of reactance which can be included in transformers are of considerable interest. The question of breakdowns in booster transformers ought not to be serious, as these would be connected on the low-tension side of the main transformers and would not be more liable to trouble in this respect than the synchronous booster or the induction regulator. The difficulties with the regulator contacts should not be serious when an auxiliary regulator transformer is used, as a portion of the contacts would be used for charging connections without breaking any power on them.

The point raised by Mr. Thompson as to the influence of the position of the booster transformer on the efficiency is interesting, but as the size of this apparatus is very small its efficiency has a very small effect on the total efficiency of the set. In the case of a three-wire system with the static booster on the low-tension side, it would, as pointed out by Mr. Thompson, be necessary to employ a booster with a six-phase secondary, but the extra cost of this should not be very much. As regards the costs given in the paper, these are expressed as percentages of the converter alone.

YORKSHIRE LOCAL SECTION, 21 MARCH, 1917.

Mr. Juhlin.

Mr. G. A. JUHLIN (*in reply*): The point raised by Mr. Selvey in connection with the spacing of the commutating poles is of importance but has no connection with the variations in the interpole flux discussed in the paper, which are due to the armature reactance of the converter. It is the practice in several cases to have certain machines for the traction supply and others for lighting and power, the transformers being arranged with tappings so that any set can be changed over from one set of bars to the other if necessary.

Mr. Shaw is quite correct in stating that rotary converters can be designed for a fairly large voltage range by providing a shunt winding on the commutating poles in addition to the usual series winding, but this arrangement does not give accurate compensation for the effect of the booster and necessitates a more liberal machine than if no booster were used. It is not impossible to obtain power-factor correction by means of a booster converter running on a traction system. If the wattless current is required to be independent of the load this can be obtained by over-excitation of the shunt field of the converter, or, if it is desirable that the wattless current should be proportional to the load, this can be accomplished by providing a series field winding on the converter. The value of the wattless current is of course fixed by the design and cannot be changed at will unless some means of changing the series fields on the booster and converter is provided.

In reply to Mr. Brown I would say that no change in the voltage ratio can be obtained by varying the design of the poles except in cases such as split-pole converters. With reference to Fig. 2 it should be noted that

Mr. Juhlin. the value of the reactance at which minimum wattless current is obtained varies with the percentage of over-compounding. I think manufacturers should not be restricted to any specified value of reactance, as due consideration must be given to the design of the converter itself when choosing the amount of reactance. Tappings in transformers are, as a rule, only employed in cases where the converter is changed from one set of bars to another, such as when the same machine is used for traction and for the lighting service.

SCOTTISH LOCAL SECTION, 20 MARCH, 1917.

Mr. Belsey. **Mr. W. J. Belsey**: I am glad that the author emphasized on page 247 the necessity for the purchaser, or, I should perhaps say, the operating engineer to look very closely into the limits of voltage required. I think that if there were a little more sympathy between the designer and the purchaser on the one hand, and the operating engineer on the other, it would be generally to the benefit of both sides. I am sorry that the author has not made the paper more complete by discussing other methods of obtaining voltage regulation. For instance, on page 241 he mentions, under (*b*), the use of an induction regulator, but does not give any details. Although the induction regulator has not been used very much in this country, it has proved a great success in the United States and therefore merits attention. Also I would suggest to him that there are such things as split-pole rotary converters, and I think perhaps he might have made the paper a little more complete in respect to these methods of obtaining voltage regulation.

Mr. Whitaker. **Mr. F. P. Whitaker**: I should like to bring out one or two points additional to those which I referred to in the London discussion (page 255). My experience is that in many cases where a long range in voltage is specified, it is the result of an excessive drop in the mains, which of course means inefficient transmission. The cure would seem to be to install rotary converter substations at such positions that the variation in voltage would be reduced to a reasonable figure, and with a corresponding gain in transmission losses. I appreciate that under this condition it may be necessary to parallel a substation with the network when the voltage on the same is very low. This can be done, either by drawing temporarily more lagging current than would be permissible for normal operating conditions, or the converter can be paralleled with the continuous-current network through a resistance, which will allow of the load being taken up gradually. As the load is taken off the network by the substation, the voltage will rise until it will be quite safe to short-circuit the last step of the resistance, when the substation will be taking its share of the load on the network. In this way 550-volt traction converters can be paralleled with the trolley line, even though the pressure [illegible] to [illegible] volts or below. Rotary converter equipments have the advantage that the reactance in series with the converter can be changed over wide limits to suit the particular duty which they may have to perform. For instance, it is advantageous to install a higher value of reactance where the demand [illegible] and that [illegible] have repeatedly to take either two or three times full-load current. I believe that the curves of [illegible] are based on the assumption that [illegible] does not change with load and itself (negative boost). Some years ago I made some tests to determine how much the axis was displaced, and I found it quite appreciable on commutating-pole booster machines when boosting. It is not quite so much for the same degree of buck, the difference being accounted for by the action of the commutating-pole flux.

Mr. Bunting. **Mr. J. H. Bunting**: I am impressed by the large number of difficulties which have to be guarded against in the design of rotary converters. Of course we have known for some time of these difficulties, but they are not always so frankly indicated as they have been to-night by the author. A pamphlet has also been issued recently by one of the firms who have made a speciality of rotary converters, in which the disadvantages rather than the advantages of this type of plant are emphasized.

Mr. Röer. **Mr. M. D. Röer**: I should like to emphasize the advantage of keeping the voltage range within as small limits as is compatible with the requirements of the service. It has often been found that machines ordered with a large voltage range are never run at their lowest or highest limits; but as the manufacturer has to allow for the whole range being obtainable, it means that the user has to pay for a larger machine and at the same time one that is not quite so efficient as the machine with a smaller range. Referring to the reactance of transformers for rotary converters, it would be very interesting to know if the author has any difficulty in obtaining as much as 25 per cent reactance, as several manufacturers do not seem inclined to include as much as this in their transformers. The author points out very clearly the many advantages of reactance control over booster control, a point which my firm have always tried to impress on their customers in connection with another type of converting plant, namely, the La Cour motor converter. In this type of plant the wattless current taken at the lower loads will be considerably smaller even than in rotary converters, due to the high value of the reactance at these lower loads.

Mr. Page. **Mr. A. Page**: In the electrical undertaking with which I am associated there are at present 97 rotary converters, aggregating 53,000 kw., and I can confirm a previous speaker's remark that very few booster converters are now being installed, as of the above 97 machines only about half-a-dozen are of the booster type. In the early days we used motor-generators and motor converters in preference to rotary converters, and of these classes of machines we have 34, giving 24,000 kw., which, in conjunction with the rotary converters, amount to a total of approximately 80,000 kw. in converting plant. For the past five years our specification for rotary converters has not varied much. In view, however, of what the author has said, we shall have to reconsider the position carefully. We know that we obtain enough regulation from reactance-controlled machines, but we do not go the length of specifying up to the 7½ per cent limit referred to in the paper: we are content with 4 per cent either way. In a large number of cases, however, the regulation might quite well be cut down to a total of 5 per cent. The

Mr. Page.

summary on page 251 shows the reactance-controlled machines to be very much better suited for general conditions than the booster type, and while cost is a most important factor when deciding which type to order, the fact that better commutation is obtained with reactance-controlled plant is, in my view, of paramount importance. There should be no great difficulty about the power factor if care is taken to specify the machine properly for the conditions under which it has to operate. It is a new experience to have a statement such as the author makes on page 250 from the manufacturing side. He says that inverted running of rotary converters should be considered as an emergency condition; the possibility of inverted running is generally used as an argument in favour of the installation of rotary converters against other forms of converting plant. Perhaps the author would explain further. A great deal of trouble has certainly resulted from the use of interpoles on converters. I suggest that one way out of the difficulty is to go back to the old designs in which there are no interpoles. I believe purchasers would be quite willing to pay the little extra that this might involve in the initial cost of the plant. In Glasgow we are experimenting just now with an automatic method of changing the flux on the interpoles. It involves a double set of brushes, one set slightly in advance of the other. Leads are taken from one set to the interpole windings on the way to the line, and from the other set the leads are connected through a resistance. We have thus two paths in parallel between the commutator and the line terminals. It is claimed for this arrangement, which is due to Professor Miles Walker, that the interpole strength will be correct for any load and voltage and that, therefore, very heavy overloads can be carried by the machine without sparking or arcing over. The experiments are not yet far enough advanced to say much about them, but we hope to obtain a satisfactory result. We are now buying a number of high-speed high-output rotary converters, and are obtaining very successful results from them, although this stage has not been reached without considerable pioneer work in the elimination of disturbing factors which had not hitherto appeared to be of importance. Our experience shows that it is better to avoid saturated reactive iron, as otherwise the commutation is very indifferent. As long as other means exist of taking care of the power factor, I would rather have a good commutating machine than one which made a high power factor possible. I should like to have the author's views on the excessively high open-circuit voltage which is sometimes experienced on rotary converter transformers, and although this is rather a digression from the subject of the paper, perhaps the author will tell us in what time a short-circuit near the substation would require to be cut out so as to avoid disturbance to the running of the rotary converters distributed over the system. The tendency of rotary converters to come out of step on the slightest provocation has, in many instances, retarded their more general use. The speed of operation of switches is, as a rule, allowing for the relay, of the order of 0·2 second. If this is too long a time from the converter point of view, then apparently every time we have a surge on the high-tension system we must expect the rotary converters to take charge of the situation.

Mr. Seddon.

Mr. E. Seddon: The object of the paper appears to be to point out the value and simplicity of reactance control when a voltage regulation of not more than 15 per cent is required on the continuous-current side. Up to this point a rotary converter is a comparatively simple machine, but if, as often happens in practice, an increased regulation is desired, then the rotary converter does not appear to be such a simple machine as is claimed for it. There are many ways of effecting this increased regulation; for instance, by means of an alternating-current booster, an induction regulator, the split-pole method, or even a continuous-current booster, all of which are more or less complications. Most engineers are, I believe, agreed that from an operating point of view the synchronous motor-generator is the ideal machine; at any rate it gives us all the regulation required in practice, and the power factor is under complete control, but unfortunately the efficiency is low. On the other hand, the simple rotary converter has poor regulation but its efficiency is high. It appears that we cannot combine all these good qualities in one machine without introducing complicated accessories. I think the case can be well met by the motor converter. Here we get almost the same regulating qualities of the motor-generator with only a difference of about 1 to $1\frac{1}{2}$ per cent loss in efficiency as compared with the rotary converter. I am speaking of machines of about 1,000 kw. There are no heavy currents to be collected at the slip-rings. There is only one rheostat to operate and the voltage can always be relied upon to build up with the correct polarity. Of course there is no doubt that the strong point of the rotary converter is its high efficiency, and for this good feature it will continue to hold its own.

Mr. Whysall.

Mr. F. H. Whysall: My interest centres on the question of practice, and I am glad to feel that in connection with the undertaking which I represent we have carried out our extensions on the lines advocated by the author. All our rotary converters are reactance-controlled six-phase machines (with the exception of one 75-kw. inverted machine which has a continuous-current booster). In the case of two rotary converters we have a middle-wire booster introduced for balancing purposes on a three-wire lighting system. This middle wire is connected from the centre point of one of the low-tension transformer coils to the armature of the booster, and from the armature of the booster through a series field. In a third unit of this size (500-kw.) the booster armature only is in series with the middle wire, and the shunt field has been fitted with a potentiometer resistance to give hand-control of the middle-wire current. Eight of the rotary converters are of the self-synchronizing type and the remainder of the hand-synchronizing type, the synchronizing being done on the high-tension side. In the case of the small three-phase inverted converter with a continuous-current booster mounted on the same shaft, this set was installed at the beginning of our alternating-current supply when there was no alternating-current plant available for long-distance transmission. With this set it was possible to maintain unity power factor and constant speed with a range on the continuous-current side of the system of 500/560 volts and at the same time maintain the constant voltage of 3,300 on the outgoing side of the transformer. In my opinion the reactance-controlled type of converter is the most suitable, provided the conditions are such that the voltage regulation would [illegible] the 15 per cent [illegible]. [illegible] and are [illegible] the [illegible] of [illegible] to [illegible]. The [illegible] is carried out satisfactorily and a variation of about 10 per cent is all that is necessary under normal working conditions. Two-thirds of the machines are installed on consumers' premises for two-wire working with a continuous-current voltage range of 200–240 with level compound characteristics, the compounding effect being necessary on account of the very heavy intermittent loads which the service requires. I refer to shipyards and engineering works using 200- to 250-h.p. air compressors accelerated from standing to full load within 20 seconds and automatically controlled. The voltages on the lighting and traction systems where the rotary converters are used for either service are fortunately 500-560 volts on the outers for lighting on a three-wire system and 540 volts for traction, so that no alternating-current boosters are required. On the high-tension side of the transformers 2½ per cent tappings are left to enable the same range at lower or higher voltages, say 480 to 520 volts. Our experience is that the higher range is only required during the winter months and little trouble is involved in changing from one set of tappings to another at the beginning or end of the season. Where two separate ranges of voltages are required, it seems to me it would be preferable to install a selector tapping switch or plug arrangement on the high-tension side of the transformer, provided the voltage range did not exceed 50 volts. If a larger range than this were required there would be no alternative but to install an alternating-current booster regulation owing to the large amount of reactance which would be required, which on low load would give a large lagging current. Although the author shows clearly the limitations of converting plant as a means of power-factor correction on loads other than that carried by itself, there is a distinct tendency for operating engineers to be tempted to over-excite the fields of the rotary converters under the reactance control with the intention of improving the power factor to compensate for the wattless currents which may come from other parts of the system. Experiments have demonstrated that the heating of the rear tap coils on the armatures of six-phase rotary converters have been so great, more especially on overloads at leading power factors, as to make it rather a risky proceeding. As an instance, if 50 per cent overload at 95 per cent leading power factor be taken on the rotary converter, the heating is nearly 4½ times that of full-load heating at unity power factor. The inherent good voltage characteristics of converters are at times rather embarrassing, especially when [illegible] with a continuous-current network at nearly full voltage after a [illegible]. In this connection it has occurred to us that, with lower voltage and frequency occurring simultaneously, trouble might be caused due to resonance being set up in the circuit. I should be glad if some information could be given on this point. It would be interesting to have a [illegible] split pole and [illegible] type.

Mr. [illegible] Hining: There is a [illegible] that I want to mention as being one disadvantage of the reactance-controlled rotary converter not mentioned by the author, and that is the question as to where the shunt-field rheostat should be fixed. If it is fixed adjacent to the alternating-current control panel of the machine, for ease in synchronizing, it is in the wrong place for continuous-current voltage regulation, as usually the a.c. and c.c. control boards are placed at opposite sides of the station—some distance apart anyhow. If two rheostats are fitted, one near the a.c. panel and one near the c.c. panel, the length of the field connections and the two rheostats are a possible source of trouble. With booster control, of course, the main-field rheostat is fixed adjacent to the a.c. panel for ease in synchronizing, whilst the booster-field rheostat is fitted near to the c.c. voltage control. This may appear to be a small matter and therefore has not been mentioned in the paper, but it seems to me that it is rather important from the operator's point of view.

Mr. W. E. Hind (*communicated*): It would seem regrettable that more attention has not been paid in the paper to other possible methods of control and their advantages and disadvantages. In cases such as that mentioned in the paper where two different ranges of voltage are required, it seems self-evident that the use of two tappings on the transformer has such great and immediate advantages that one would expect it to be universally employed. By reducing the range of regulation required from the reactance, or the booster, or whatever other method is employed, it evidently simplifies and very much cheapens the first cost of the apparatus required. It would seem, however, that for the fine regulation required in addition to the tappings, there are other methods worthy of consideration, at any rate from the theoretical point of view. One of these is the use of a continuous-current booster instead of an alternating-current one, and although the difficulties of designing a suitable commutator for such a machine may in some cases be prohibitive, one would imagine that there must be many cases where the continuous-current booster would give an ideal method of regulation. It would be free from the objections of the reactance method in so much as it would give a greater range of regulation and would allow of control of the power factor. It is true that if connected to the rotary converter shaft it would still introduce increased difficulties in the commutation in the same way as described for the alternating-current booster. It is quite conceivable, however, that cases would occur where it would be possible and convenient to employ a motor-driven continuous-current booster. Since writing the above, I have read Mr. Brazil's remarks in the London discussion (page 253) which show that a continuous-current booster can in some cases be used perfectly satisfactorily. Another method of some theoretical interest would be the use of a reactance in the line, arranged so that the amount of reactance could be varied at will. It would seem that such an arrangement if found possible in practice would do away with some of the difficulties now experienced in the use of voltage control by reactance, and would probably make this the ideal method of regulation in cases where too large a range of the regulation was not required. There is no doubt that the simplicity of reactance control, as mentioned by the author, gives it great advantages over other methods in those cases where it can be used, and the regulation of the amount of reactance in circuit would considerably increase these advantages.

Mr. Juhlin. Mr. G. A. JUHLIN (*in reply*): The point raised by Mr. Belsey with reference to the necessity of close co-operation between the operating engineer and the designer is of such importance that it cannot be too strongly emphasized. To have dealt fully with all the different schemes of voltage regulation would have been far too lengthy for a single paper and for this reason it was limited to the most common types of control.

Mr. Whitaker's remarks in connection with paralleling a converter with the network when the voltage is very low are of importance. In the paper I drew attention to the fact that very much larger wattless currents can be carried by the converter for a short time than for continuous operation, and I think this point should be emphasized. The curves showing the ratios of armature copper losses are based on the assumption that there is no displacement of the armature. Unless very small air-gaps are used the displacement will be very small for the values of boost usually met with.

Referring to Mr. Bunting's remarks, I think it should be made clear that the difficulties mentioned in the paper with regard to the booster type of rotary converter do not exist in the simple converter and are therefore not inherent in the converter but simply due to the particular system of voltage control. I do not think my remark that voltage regulation of rotary converters requires close consideration can be construed to emphasize the difficulties of the rotary converter. I wished to emphasize the possibilities and advantages of the reactance-controlled type as compared with the booster type, and that the former type of machine has in my opinion not received the consideration it deserves.

In reply to Mr. Röer's question as to the amount of reactance which can be included in a transformer, I would say that we have no difficulties in obtaining 25 per cent reactance.

The figures given by Mr. Page are very interesting and indicate that the rotary converter is holding its own as converting plant for large distributing systems. It is very interesting to find that Mr. Page considers a total regulation of 5 per cent in a large number of cases to be sufficient. Regarding the question of running rotary converters inverted, my remark that this should be considered to be an emergency condition may be open to misunderstanding. There is of course no difficulty in running converters inverted except where special conditions as regards voltage variation are required, and the meaning I wanted to convey was that each case should be considered on its merits, as it is difficult to discuss the most suitable system in a general way. It is somewhat difficult to make a general statement on the influence of reactive iron on the commutation as there are many machines with transformers having saturated reactive iron running exceedingly well. The open-circuit voltage of the transformer for an overcompounded machine may be high owing to the machine being designed to carry low wattless currents at full load and above, which means that the transformer voltage has to be reduced at light loads by means of wattless currents. It is not very promising to look for circuit breakers which would clear a fault quickly enough to avoid disturbances on the system. Very little trouble is experienced with modern rotary converters as regards falling out of step. Improved dampers, etc., have eliminated this trouble to a great extent.

I do not think Mr. Seddon is correct in stating that the motor converter has almost the same qualities as the motor-generator in respect to voltage regulation. As a matter of fact the motor converter has, like the rotary converter, a constant conversion ratio, and voltage regulation must therefore be obtained by some special means such as reactance control, a booster, or an induction regulator. The motor converter has to be provided with slip-rings which will be in circuit continuously unless a short-circuiting device is provided. The slip-rings do not of course carry the full current as in the rotary converter. As regards the certainty of the voltage always building up in the right direction, there is no difficulty with the modern converter in this respect.

Mr. Whysall's remarks are exceedingly interesting as they show that reactance control can be adopted with success for general power and lighting service as well as for traction work. Referring to the question of resonance being set up due to falling voltage and frequency, there is less possibility of resonance at the lower frequency than at the higher, as the natural frequency of systems of the size usual in this country is very much higher than the running frequency.

In connection with Mr. Hird's communication, the objections to the use of the separately-driven continuous-current booster are the increased first cost and maintenance. The variable reactance would be a complicated and expensive arrangement and would not materially improve the conditions as regards voltage control.

DISCUSSION ON

"PRINCIPLES INVOLVED IN COMPUTING THE DEPRECIATION OF PLANT."*

NEWCASTLE LOCAL SECTION, 12 MARCH, 1917.

[illegible] [illegible]gst those who have control of expenditure [illegible] spend extra capital to obtain low annual charges. Too often this is disregarded. A comparatively small addition to the first cost may frequently so reduce the annual charges that the additional first cost incurred may actually be entirely wiped out in a very short time, and yet the extra capital required may not be forthcoming. In the discussion of the paper in London Mr. Highfield suggested [illegible] that the difference of opinion between engineers and accountants on this subject of depreciation is due to the fact "that the engineer is generally thinking of the plant and its efficiency, whereas the accountant's interest is mainly in the efficiency of each sovereign invested in the business." I think that this is quite true, and the thought suggests that one step in the removal of that difference of opinion is to give the engineer a little more interest in the sovereign and the dividend derived from it, i.e. he should be much more largely concerned with the [illegible]. The authors have emphasized that the paper deals with principles, but in discussing such a paper it appears difficult to exclude entirely the application of those principles in practice, and I should like to ask the authors' opinion on a matter which I think is not entirely irrelevant. There are numerous cases where it is necessary to install plant which will remain spare for some time. In order to bring that spare plant into use a certain small expenditure is necessary. The value of the plant is not increased by such expenditure (except in so far as its value may be regarded as being enhanced by virtue of its being made [illegible]) and I should like to know whether the authors consider such a charge should be met out of [illegible] capital. The question of depreciation is of [illegible]e, and so closely concerns engineers of [illegible] I hope it will not be allowed to drop. I [illegible]

[illegible]

Mr. Beard.

[illegible] systems really appear to be a mere juggling with figures in order to get certain supposed advantages which seem difficult of precise expression. Possibly one reason which is at the back of these alternative methods is that to some extent they simplify book-keeping and the users of them feel that in the long run the results are sufficiently accurate for everyday use. There is, I think, some justification for this attitude in that I cannot conceive how any really accurate estimate can be made of the physical lives of most forms of engineering plant, still less of their economic lives. In consequence the mathematical precision of the sinking fund method seems somewhat pedantic in the light of the exceptionally rough data on which it is based. The life of telegraph poles, which is the instance cited by the authors, is, I agree, comparatively easy of determination, but even in their case there are many disturbing factors, although there are many thousands of poles of all ages on which to base calculations. If in such a simple instance only an approximate figure can be obtained, I do not see how any approach to accuracy could be made in the case of more complicated items, such as turbo-alternators, transformers, cables, etc.

Mr. Armstrong.

Mr. C. P. **ARMSTRONG**: In items (3) and (4) near the top of the second column on page 140 the authors set out what may be termed the essential conditions necessitating the plant being charged with a yearly sum in order to cover certain maintenance and other expenses. The first of these two items involves the setting aside of so much money yearly as may be decided upon under any of the three methods mentioned on page 141, such sum being provided for depreciation. It occurs to me that a somewhat involved condition may arise in a case where, say, 25 per cent of the plant can be profitably renewed before the expiration of its full useful life. Assuming such a case, we have a capital value increased so far as plant is concerned, and of course earning power as well. In such a case what method would be adopted to provide for the sinking fund charges? Would the depreciation fund be split into two—one part to cover depreciation on the renewed plant and the other on the old plant, or would a general average value be taken of the whole? It seems, in any case of the kind indicated, that a fresh calculation must be made to decide what amounts shall be placed to the credit of the sinking fund. If so, what form would such calculation take?

Mr. Ho

Mr. A. C. **HOVEY**: Speaking from the engineer's point of view, one is impressed with the divergent views of accountants, financiers, and engineers on the subject of depreciation. If there were co-operation as is suggested, it would be greatly to the advantage of any industry. It is very difficult for men of different professions to realize the importance of each other. Perhaps that point may be illustrated in this way. When an engineer puts forward

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* [illegible]

Mr. Hovey.

his estimates and his suggestions he frequently does so (especially in rising industries) with a view to the future, and often his estimates for some considerable time ahead will appear to be not so satisfactory as he had optimistically suggested in the first instance. When that occurs the engineer has to bear criticisms which are sometimes not altogether complimentary with regard to his financial knowledge. The gas industry has been very severely dealt with lately by Parliament in anything asked for with regard to improved methods of finance. The authors have mentioned the renewals fund as one of great importance, but in some cases in recent years where there has been a renewals fund in past private Acts of Parliament, it has been struck out and will not be allowed in future. It is of great importance—especially for large undertakings—to incur a considerable expenditure in certain years to get through the work, and it is a great pity that such a fund should have been done away with. I should just like to add, with regard to the future, that it is to be hoped the gas and electrical industries will be more closely associated, particularly on main grounds such as the subject of depreciation. The gas industry has recently been formed into one very strong body which has a national council. All the trade and professional men are there represented and it is to be hoped that in a matter of this sort if the industries act together, benefit will accrue to them both.

Mr. Turnbull.

Mr. C. Turnbull: Some years ago, when the Post Office was taking over the undertaking of the National Telephone Company, there was much argument regarding the straight line and sinking fund methods of calculating depreciation. In the arbitration, a railway manager gave evidence in favour of the straight line method, as being commonly used by railway companies. That is not a great recommendation, for railway companies' tariffs are always rising, and it is well known that they have immense amounts in their capital accounts which do not represent live assets. The sinking fund method with its power of growing by means of compound interest, if adopted by railway companies, would enable them in time to pay off their "unrepresented" capital, which the straight line method, with the small contributions made, has not done. I think that there is a distinct difference between depreciation and maintenance. Depreciation may be defined as the loss of value that takes place in plant which is efficiently maintained. In electrical undertakings depreciation mainly consists of obsolesence. Although plant depreciates with time, we should not forget that there is also appreciation in electricity undertakings owing to the fact that as consumers are added the undertaking earns more profits. Hence a municipal undertaking should not be required to make full provision for depreciation during the early days before the business will stand it. Some towns are handicapped by the large sums which they are compelled to pay into their sinking funds. This is generally held up as being sound finance, but it may not be, because where the moneys are invested at compound interest they accumulate rapidly even where the sums put by are comparatively small. A reference to tables will show that £4 1s. 7½d. put by per annum at 3½ per cent will redeem £100 in 18 years; £3 1s. 10½d. in 22 years; £2 11s. 4¼d. in 25 years; and £1 18s. 9d. in 30 years. Experience with gas works and other undertakings goes to show that depreciation in value is not so rapid that the concern is valueless in 30 years, and we may conclude that an electricity supply works which is paying off its capital in, say, 25 years is in at least as good a position as the ordinary gas works, and probably far better off than many of them.

Mr. Turnbu

Mr. Nichols

Mr. G. Nicholson: The policy of providing out of profits a sum sufficient to write off the plant during the term of its physical life is undoubtedly sound. So far as providing for improvements is concerned, however, the position is somewhat different, as shown below:—

(1) Such improvements will presumably result in increased efficiency and capacity, and therefore in increased profits. Why, then, should the profits of the earlier years be reduced by charging, against the same, improvements which will have the effect of increasing the profits of later years. That is certainly penalizing the shareholders of the early years and benefiting those of later years abnormally. The original shareholders might legitimately complain that the profits which their capital had earned had been utilized to provide improvements which they themselves did not get the full benefit of, and that later shareholders were obtaining a benefit at their expense, and for which such later shareholders had not contributed any capital. In a new concern, of course, the original shareholders take the greatest risk, as they have no past results to guide them when contemplating investment.

(2) Of course, if capital is charged with the same, it means that a higher revenue charge immediately commences to accrue so as to write down such increased capital, but as there is a larger revenue also accruing, this is not an additional burden.

(3) The charging of improvements to revenue in the early years having the effect of keeping down dividends is bound to re-act when new capital is required, and it might be found very difficult to raise new capital even for necessary extensions (not improvements), which difficulty might seriously retard the development of what might otherwise have been a progressive concern.

(4) Having regard to the prices obtainable for power and lighting supplies, and to the cost of labour and materials, I do not think there are many electrical undertakings in this country operated by limited companies who are able out of profits (*a*) to provide for depreciation based on the physical life, (*b*) to provide for improvements based on the economic life of the plant, and (*c*) to pay a fair dividend to shareholders.

(5) Whilst it is of the utmost importance that every opportunity should be taken to strengthen the financial position of an undertaking, yet the management have a duty to perform to the shareholders, and therefore I am of the opinion that improvements of the nature indicated are more fairly treated as capital as and when they are incurred.

I consider that the authors have fully substantiated their claim that the sinking fund basis is the correct one for [illegible] purposes. Speaking generally from my experience of a large undertaking having a capital expenditure account of about 3 million pounds and where further capital is being expended practically from day to day, I consider the only method to adopt would be the "equated life" and to treat the plant as a whole.

Messrs. [illegible] and W. W. Cook (*communicated*) *reply*. For the reasons given on page 226 we confine our reply to two points only.

With regard to the question of the cost of bringing spare plant into use, each individual case must be considered on its merits and the only general rules that can be laid down are that if construction work has been deferred the completion of it will be a capital charge and that if for any cause it is necessary to do again work which has already been done once the cost should probably be charged to revenue.

Messrs. G
and Cook.

The difficulty of estimating lives has already been referred to, but in reply to Mr. Beard we must again emphasize the impossibility of considering alternative schemes without making the best possible estimates of lives. This is a really practical matter of everyday importance to engineers dealing with large plants, who must select plant on an economic basis if they realize their responsibility, and it is not by any means the academic question which Mr. Beard appears to think.

PROCEEDINGS OF THE INSTITUTION.

598TH ORDINARY MEETING, 12 APRIL, 1917.

(Held in the rooms of The Institution of Civil Engineers.)

Mr. C. P. Sparks, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 22nd March, 1917, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The President: I have to announce that the Institution of Civil Engineers have kindly placed their Reading Room and Library at the disposal of our members whilst we are in temporary premises. Unfortunately the books of our own Reference Library will not be available to members, with the exception of a limited number of works of reference and bound volumes of periodicals, but we have been able to take with us our Lending Library, and, on application to the Secretary, any books in the Lending Library can be sent to members as in the past.

A paper by Mr. C. Vernier, Member, entitled "Wayleaves" (see page 329), was read and discussed, and the meeting adjourned at 7.45 p.m.

599TH ORDINARY MEETING, 26 APRIL, 1917.

(Held in the rooms of The Institution of Civil Engineers.)

Mr. C. P. Sparks, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 12th April, 1917, were taken as read, and were confirmed and signed.

Messrs. J. O. Girdlestone and J. H. Johnson were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

Elections.

Associate Members.

Butcher, Percy Henry C.
Finney, Sydney Henry.
Kinnear, Robert Inglis.
Royle, William.
Spurr, Reginald Dade.

Graduates.

[illegible]
Flanagan, Frederick, Sub-Lt., R.N.V.R.
[illegible]
Welden, William Audley.

Students.

Claeys, Walter Ralph E.
Corkling, Robert William.
Ellercamp, Wilfred Alan H.
Humm, Robert William.
Martin, Reginald Ian.
Newburn, Edgar Allan.

Transfers.

Associate to Member.

Kenny, Thomas Richard Davis.

Graduate to Associate Member.

Carter, Arthur Francis.
Macilwraith, George Melven.
Riley, Tom.

Student to Associate Member.

Flight, William Stanley.
Jackson, Forbes, Lieut., R.N.V.R.

Student to Graduate.

Ball, William James E.
Perrett, Arthur Harold.
Warner, Cecil Etheridge.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : A. H. F. Boughey, J. Burns, W. W. Cook, S. Evershed, F. Gill, H. V. Henniker, S. Insull, J. E. Kingsbury, W. E. Lane, E. K. Scott, M. G. Simpson, C. P. Sparks, and W. C. P. Tapper.

Building Fund : Professor A. Hay, D.Sc., W. McGeoch, and A. Wright.

Library : The Association of Supervising Electricians, The Channel Tunnel Company, A. T. Dover, Killingworth Hedges, Professor A. E. Kennelly, D.Sc., J. W. Meares, W. H. Nottage, and the Société Internationale des Électriciens.

Mr. J. O. Girdlestone, Mr. F. B. O. Hawes, and Professor J. T. MacGregor-Morris were appointed scrutineers of the ballot for the election of new Members of Council.

A paper by Mr. G. V. Twiss, Associate Member, entitled "High-Tension Overhead Transmission Lines" (see page 413), was read and discussed, and the meeting adjourned at 8 p.m.

INSTITUTION NOTES.

ELECTION OF NEW MEMBERS OF COUNCIL.

The scrutineers (Mr. J. O. Girdlestone, Mr. F. B. O. Hawes, and Professor J. T. MacGregor-Morris) appointed at the meeting of the 26th April, 1917, have reported to the President that they have examined the Ballot Papers and that the following have been found to be duly elected :—

President : C. H. Wordingham.

Vice-Presidents : G. W. Partridge and W. B. Woodhouse.

Honorary Treasurer : J. E. Kingsbury.

Ordinary Members of Council : L. B. Atkinson, W. A. Chamen, J. S. Highfield, Sir W. Slingo, Lieut.-Col. H. C. Sparks, D.S.O., M.C., and A. P. Trotter.

The Council for the year 1917–1918 will therefore be constituted as follows :—

President.

C. H. WORDINGHAM.

The Past-Presidents.

Vice-Presidents.

R. A. Chattock.
G. W. Partridge.
R. T. Smith.
W. B. Woodhouse.

Honorary Treasurer.

J. E. Kingsbury.

Ordinary Members of Council.

L. B. Atkinson.
J. O. Callender.
W. A. Chamen.
F. W. Crawter.
J. Devonshire.
H. Dickinson.
J. H. Gray.
H. H. Harrison.
J. S. Highfield.
Prof. T. Mather, F.R.S.
G. H. Nisbett.
W. Ll. Preece.
H. F. Proctor.
G. S. Ram.
W. R. Rawlings.
Sir W. Slingo.
Lieut.-Col. H. C. Sparks, D.S.O., M.C.
A. P. Trotter.

AND

The Chairman and Immediate Past-Chairman of each Local Section.

ACCESSIONS TO THE REFERENCE LIBRARY.

Anrep, Aleph. Investigation of the peat bogs and peat industry of Canada. 1913-14 (Canada, Dept. of Mines, Mines Branch)
8vo. 222 pp. *Ottawa*, 1915

Auckland University College. Engineering Department.

The Auckland Power House. Gas and oil driven stations. [Reprinted from "The Commonwealth Engineer," Aug., 1913]. 4to. 8 pp. *Melbourne*, 1913

Extra-high-tension insulators. The use of compound and simple motors. [Reprinted from "The Commonwealth Engineer"]. 4to. 8 pp. *Melbourne, n.d.*

Hydro-electric power in New Zealand. [Reprinted from "The Commonwealth Engineer"].
4to. 14 pp. *Melbourne, n.d.*

The Lake Coleridge power scheme, N.Z. [Reprinted from "The Commonwealth Engineer," Dec., 1914].
4to. 7 pp. *n.p.*, 1914

Some hydro-electric plants in New Zealand. [Reprinted from "The Mining and Engineering Review," Mar. and Oct., 1912].
4to. 8 pp. *Melbourne*, 1912

Babcock, E. J. Economic methods of utilizing western lignites. [United States, Dept. of the Interior. Bulletin 89.] 8vo. 73 pp. *Washington*, 1915

Bauer, L. A., and Fleming, J. A. Land magnetic observations 1911–1913, and reports on special researches. [Carnegie Institution of Washington. Researches of the Dept. of Terrestrial Magnetism, vol. 2].
4to. 284 pp. *Washington*, 1915

Bearce, E. W., and Peffer, E. L. Density and thermal expansion of American petroleum oils. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 77.]
8vo. 26 pp. *Washington*, 1916

Beaver, C. J. Address on "The personal side of engineering training," March 28th, 1916. [The Institution of Electrical Engineers, Manchester Students' Section]. 8vo. 14 pp. *Manchester*, [1916]

[illegible] High versus low antennae in radio-telegraphy and [illegible]. Bulletin of the University of Wisconsin, no. 810. Engineering experiment station.
8vo. [illegible] pp. *Madison, Wisconsin*, 1916

[illegible], A. F. A paper on electric cooking and heating. [The Association of Supervising Electricians.]
sm. 8vo. [illegible] pp. *London*, 1916

[illegible], A. V., and [illegible], H. G. Properties of [illegible] plastic fire clays. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 79.]
8vo. 34 pp. *Washington*, 1916

Board of Education. Report of the Board of Education for the year [illegible].
8vo. 110 pp. *London*, 1916

Bombay Fire Insurance Association. Wiring rules for electrical installations. [With extracts from the Board of Trade regulations, Home Office regulations for factories and workshops. Cinematograph rules [England,] and the Indian Electricity Act. (1910)].
2nd ed. revised. 8vo. 99 pp. *Bombay*, [1916]

Boughton, E. W. Determination of volatile thinner in [illegible]. [United States Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 76.]
8vo. 9 pp. [*Washington*,] 1916

British Electrical and Allied Manufacturers' Association. Engineering industry in war and peace. National meeting at the Mansion House, Sept. 20th, 1916.
8vo. 20 pp. *London* [1916]

[illegible], H. B., and Wenner, F. C. A variable self and mutual inductor. [United States, Dept. of Commerce, Scientific Papers of the Bureau of Standards, no. 290.]
8vo. 17 pp. *Washington*, 1916

[illegible], C. E., and [illegible], P. D. An investigation of [illegible]. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. [illegible].]
8vo. 37 pp. *Washington*, 1915

Some foreign specifications for railway materials: rails, wheels, axles, tyres. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. [illegible].]
8vo. 132 pp. *Washington*, 1916

Canada, Department of Trade and Commerce. Canada: The Country of the Twentieth Century, by Watson Griffin.
8vo. 283 pp. *Ottawa*, 1915

Canada, Department of Mines. Mines Branch. Description of the laboratories of the Mines Branch of the Department of Mines, Ottawa.
8vo. 57 pp. *Ottawa*, 1916

Corin, W. Power requirements and resources of New South Wales. [Paper read before "The Electrical Association of Australia," New South Wales Section, [illegible] 1915].
8vo. 53 pp. *Sydney*, 1915

Dover, A. T. Electric traction. A treatise on the application of electric power to tramways and railways.
8vo. 683 pp. *London*, 1917

Garrett, J. C. M. Part-time secondary education. [An address delivered before the "United Workers" on [illegible], 1915.]
8vo. [illegible] pp. *Manchester*, 1915

[illegible] Electric switch and controlling gear. A handbook on the design, manufacture, and use of switchgear and switchboards in central stations for [illegible].
8vo. [illegible] pp. *London*, 1917

General Electric Company. Notes relating to the electrical machinery sections of the Standardization Rules of the American Institute of Electrical Engineers.
sm. 8vo. 24 pp. *Schenectady*, [1916]

Gott, A. E. The Sperry gyro-compass. A brief description of its principles and operation.
8vo. 13 pp. *London* [1916]

Goudie, W. J. Steam turbines. A text book for engineering students.
8vo. 720 pp. *London*, 1917

Hadfield, Sir Robert. The Advisory Council for Scientific and Industrial Research. [Reprinted from the "Iron and Coal Trades Review," May 19, 1916].
4to. 4 pp. [*London*, 1916]

Herbert, T. E. Telegraphy. A detailed exposition of the telegraph system of the British Post Office.
3rd ed. 8vo. 1,005 pp. *London*, 1916

Hirobe, T., Ogawa, W., and Kubo, S. Electrical insulating properties of transformer oil. [Electro-technical laboratory, Imperial Dept. of Communication. Tokyo, Japan.]
8vo. 18 pp. *Tokyo*, [1916]

Home Office. Memorandum by the Electrical Inspector of Factories on the electricity regulations. (Factory and Workshop Acts, 1901 to 1911.)
2nd ed. 8vo. 84 pp. *London*, 1916

Hulett, G. A., and Vinal, G. W. Studies on the silver voltameter. [United States, Dept. of Commerce, Scientific Papers of the Bureau of Standards, no. 240. Reprinted from Bulletin of Bureau of Standards, vol. 11.]
8vo. 20 pp. *Washington*, 1914

India. Annual report on the posts and telegraphs of India for the year 1915–16, with a review of the progress of the department for the quinquennial period, 1911–12 to 1915–16.
4to. 65 pp. *Simla*, 1916

Institute of Radio Engineers, The. Report of the Committee on Standardization for 1915.
8vo. 31 pp. *New York*, 1916

International Electrotechnical Commission. Russian Electrotechnical Committee. Publ. 19, International specifications for electricity meters.
4to. 71 pp. *Petrograd*, 1915

International Engineering Congress, San Francisco, 1915. Transactions.
11 vols. 8vo. *San Francisco, California*, 1916]

[1] The Panama Canal, 2 parts.
[2] Waterways and irrigation.
[3] Municipal engineering.
[4] Railway engineering.
[5] Materials of engineering construction.
[6] Mechanical engineering.
[7] Electrical engineering, and hydro-electric power development.
[8] Mining engineering.
[9] Metallurgy.
[10] Naval architecture and marine engineering.
[11] Miscellany.

James, W. H. N. Alternating currents in theory and practice.
8vo. [illegible] pp. *Cambridge*, 1916

Japan. Statistical report of electric undertakings in Japan, [illegible] 1914.
2 vols. 8vo. *Tokyo*, n.d.

Jones, E. D. The administration of industrial enterprises, with special reference to factory practice.
8vo. [illegible] pp. *London*, 1916

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HIGH-TENSION OVERHEAD TRANSMISSION LINES.

By G. V. Twiss, Associate Member.

(*Paper first received* 8 *November*, 1916, *and in final form* 7 *February*, 1917; *read before* THE INSTITUTION 26 *April*, *and before the* BIRMINGHAM LOCAL SECTION 25 *April*, 1917.)

SYNOPSIS.

1. Introduction.
2. General design of transmission lines.
    - Spacing of conductors :—
        - Arrangement.
        - Clearances : (*a*) between conductors, (*b*) between conductors and supports.
    - Tension and loading of conductors and consequent effects.
        - Comparison of wind and ice loadings.
        - The economical span length.
        - Factors of safety.
    - Earth and lightning wires.
    - Loads at terminal, angle, and intermediate positions.
    - Choice of type of insulators having regard to mechanical loads and voltages.
        - Special arrangements for Merz-Hunter system.
3. Particular design of transmission line material.
    - Poles : Wood, tubular, lattice steel. Testing.
    - Line insulators.
        - Electrical design (normal working ; surges) : Pin type ; suspension type (Hewlett ; metal hooded).
        - Mechanical design : Expansion and contraction, stresses, loads ; pin insulators, attachment to pins ; suspension insulators.
    - Testing of insulators :—
        - Routine : electrical, mechanical.
        - Design : electrical, high-frequency, mechanical, mechanical-electrical.
        - Deterioration : "Megger," dye, mechanical-electrical, heat.
        - Concluding remarks to insulator section.
    - Clamps, etc., for straining, suspension, pin insulators, earth wires.
4. Conclusion.

1. INTRODUCTION.

Several, recent, large power schemes abroad embodying transmission lines of the highest voltages[*] have been engineered from this country, and our share of such engineering is likely to increase. Moreover, in view of the necessity for conservation of the coal resources of this country and the fact that we must hold our own in industry against countries possessing abundant and very cheap power—derived from water and transmitted by high-tension transmission lines—it is quite possible that we may yet have transmission lines working at 100 kilovolts or so in this country. The present movement in regard to the linking up of power stations may indeed necessitate transmission lines at voltages much higher than those used at present ; and there is still the possibility of developments such as the transmission of power in bulk at high voltages from coal areas, as foreshadowed by Dr. Ferranti in his Presidential Address to this Institution.[*] Hence the subject of transmission lines at the highest pressures is of increasing concern to us.

Transmission lines abroad and in the British Dominions, including those engineered from this country, show marked differences from those at home, as is shown in Fig. 1. The respective voltages, whilst accounting for the length of cross-arm, do not entirely account for the other differences. If, therefore, a 100-kilovolt line had to be built in this country, upon which practice would the design be based ?

This is merely an interesting example of one of many divergencies and open points which exist in transmission-line practice of to-day, and these and other matters are considered below.

2. GENERAL DESIGN OF TRANSMISSION LINES.

SPACING OF CONDUCTORS.

Arrangement.—Conductors may be arranged in any of the ways shown in Fig. 2. The diagrams show arrangements for double circuits, but for single circuits half of each diagram may be read.

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[*] Tata Hydro-electric Power Co. (see paper by Mr. A. Dickinson, *Journal I.E.E.*, 1915, vol. 53, p. 693) ; Victoria Falls & Transvaal Power Co. (see paper by Mr. A. E. Hadley, *Journal I.E.E.*, 1913, vol. 51, p. 2) ; Hora Hora Hydro-electric scheme of the Waihi Gold Mining Co., etc.

[*] *Journal I.E.E.*, 1911, vol. 46, p. 6.

[illegible] the choice of arrangement of conductors are as follows :—

(1) Electrical considerations.

(2) Mechanical considerations, such as :—

- Possibility of wires swinging together.
- Leverage on the cross-arms and poles.
- Snow, either unevenly weighing down the conductors, or falling off and causing the conductors to foul one another or to come too close together.

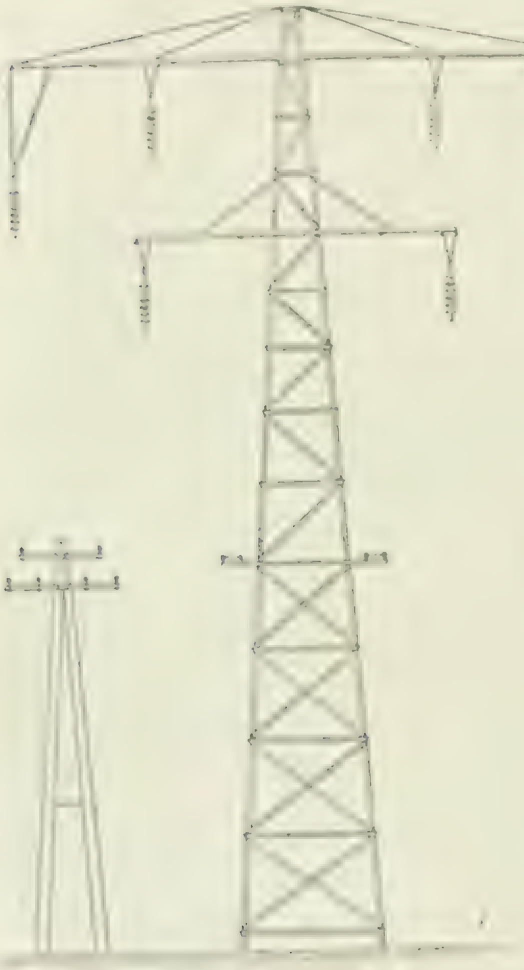

FIG. 1.—[illegible] lines at home and abroad.

From the electrical point of view, the A and B arrangements in Fig. 2 are equally satisfactory. In any case, however, the maintenance of an equilateral triangle is not of the greatest importance, and in some of the largest [illegible] made to obtain a [illegible] arrangement†.

From the point of view of swinging together, [illegible] is the best, [illegible] whilst as regards snow [illegible] and the A arrangement is the best. The B arrangement, however, is equally good if the base of the triangle is tilted slightly as in B2.

It would appear, therefore, that the B arrangement with the base of the triangle slightly tilted is the best arrangement for double circuits, as it gives the shortest poles and the shortest cross-arms compatible with the absence of swinging together and snow effects, and incidentally maintains the triangular arrangement—which is desirable if nothing is lost thereby.

For pressures in the neighbourhood of 100 kilovolts this arrangement makes the top cross-arm somewhat long, as shown in Fig. 1. As a matter of fact the design of these long cross-arms was questioned when Mr. Hadley read his paper before the Institution, in which he illustrated similar towers.* The triangular members to which the insulator is fastened at the extreme of the cross-arm are, however, pivoted and form a sling† which, having no movement laterally, is free to swing in the line direction; hence, in the event of a conductor being broken on one side, the sling and the suspension insulator swing into the span, thereby materially reducing the tension. The author, who was concerned with the design of these masts, was present at tests conducted upon them when a torsional couple was applied to the long cross-arm to simulate the effect of the breakage of the conductors on opposite sides, and the mast withstood this test satisfactorily.

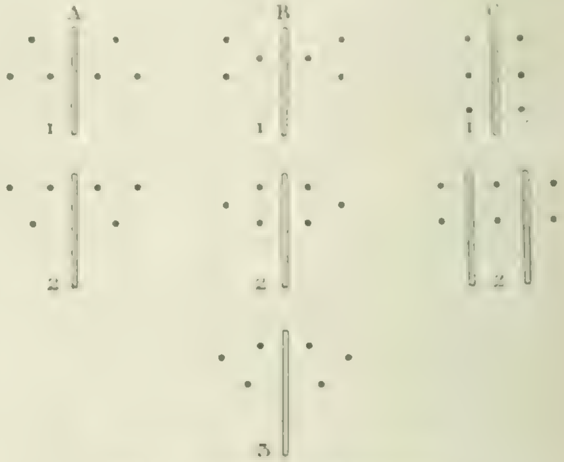

FIG. 2.—Arrangement of conductors.

It will be noticed that in this design of mast the continuous taper of the pole gives the necessary tilt to the base of the triangle to obviate trouble due to snow on conductors.

For single-circuit construction the horizontal arrangement (C3 in Fig. 2) appears to have advantages, as the pole is the shortest possible and there is no possibility of the conductors fouling owing to snow. It requires, however, the maximum length of cross-arm, and triangular spacing as A or B is more frequently used in practice.

Considerations [illegible] affecting clearance between conductors are as follows :—

(1) Mechanical, i.e. the possibility of wires swinging into contact or dangerously close together.

(2) Electrical considerations, which with the very high voltages must include the possibility of corona loss.

In regard to (1), the possibility of wires swinging together will of course depend upon the relative positions of the wires, whether horizontal, vertical, or triangular.

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* [illegible] Hadley [illegible]

† [illegible]

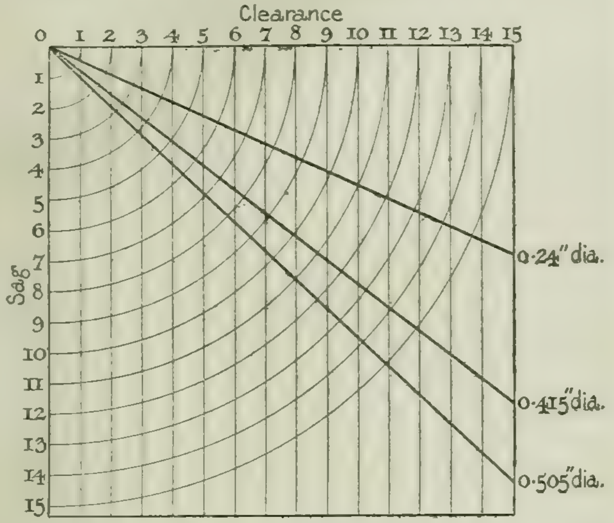

FIG. 3.—Curve of clearances.

Note. Figures of sag and clearance may be read in any unit, i.e. in feet, inches, etc. Conductor curves are calculated upon Board of Trade regulations. 0·505 in. diam. = 19/0·101″, 0·415 in. diam. = 19/0·083″; 0·24 in. diam. = 7/14 S.W.G.

There seem to be no definite rules in regard to the clearance necessary for mechanical reasons, and the following discussion is given tentatively with a view to arriving at some basis.

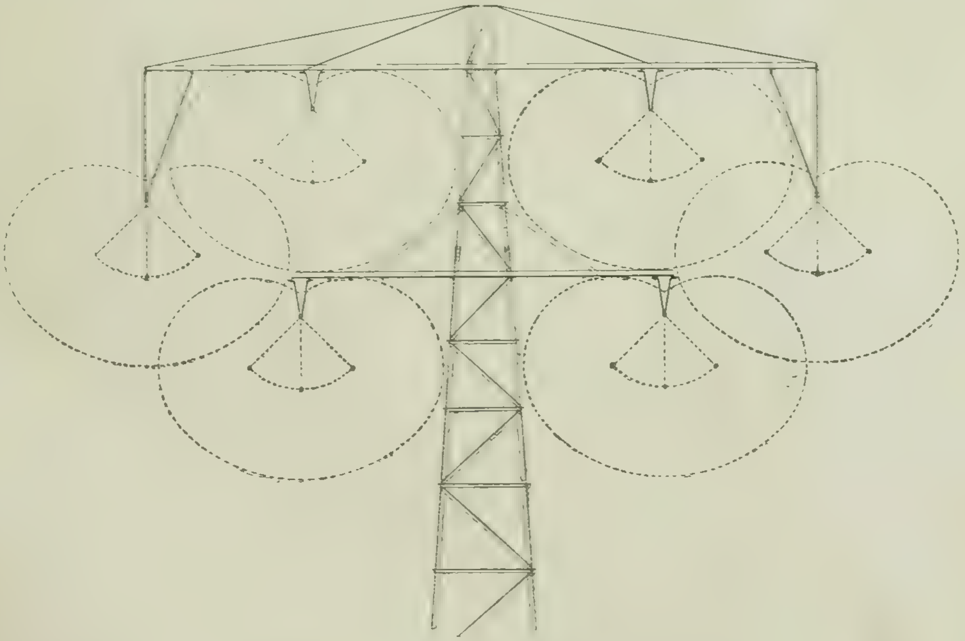

FIG. 5.—Clearances with suspension insulators.

Clearance with horizontal arrangement.—Wind may blow at any angle to the conductors, and with different velocities at different points in any span; hence a set of sagging conductors of small weight relatively to their wind area (for instance, very small wires, especially if of light material such as aluminium) will tend to swing irregularly, i.e. out of phase, and might touch or come dangerously close unless well spaced apart. Wires having a greater weight relatively to their wind area (i.e large wires, especially of heavy material such as copper) will have a more dead-beat action and will tend to swing less out of phase, i.e. more synchronously, and consequently need not be spaced so far apart to obtain the same security against short-circuits.

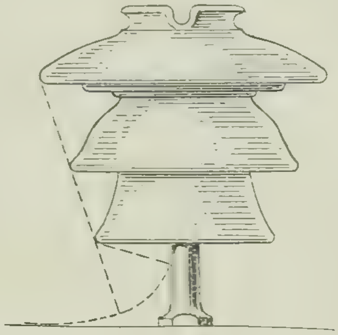

FIG. 4.—Method of determining length of pin.

This out-of-phase swinging is best stated as an angle, and as the wires cannot very well swing to diametrically opposite positions, the maximum angle of out-of-phase swinging for the lightest and smallest wires will be, say, 90°. For heavier and larger wires it will of course be less, depending upon the ratio of wind load to weight. This ratio may, however, also be expressed as an angle, namely, that made with the vertical by the resultant of the wind load and the weight. The maximum value of this angle would also be 90° for the hypothetical case of a wire with no weight, and the heavier and larger the wires the smaller will be this angle. From this point of view, the relation- [illegible] be used as an absolute indication of clearance by making the latter equal to the product of the sag and the sine of the angle made with the [illegible] of the wind area and the weight.

[illegible] must obviously vary with the tension at which the conductors are strung, [illegible] material of the conductor, and the sag, and all these conditions are considered in this method.

[illegible] Fig. 3 has been calculated upon this basis and appears to give clearances which are comparable with the best practice.

[illegible]—Here the chief [illegible] the possibility of the wires being unequally borne down by ice or snow, or of the wind lifting or depressing the wires unequally. The clearance will therefore bear a relationship to the span, and a clearance of 1 ft. per 100 ft. of span would appear to be a good rule.

Clearance with triangular arrangement.—If the base of the triangle is horizontal the clearance would be settled as above for horizontal clearance; if vertical, then the vertical clearance would settle it, and for all other cases the clearance could be adjusted accordingly.

In regard to (2) above, namely, electrical considerations, formulæ are already available.

The final clearance chosen for a given case would be whichever proves to be the greater, that indicated for electrical or for mechanical considerations; and in certain cases the necessary clearance between the conductors and the pole may necessitate a greater clearance between the conductors than that above obtained.

[illegible] ance between a conductor and the [illegible] ctor to the cross-arm should not be less [illegible] ce from the conductor round the insulator [illegible]. Fig. 4 shows how the correct length of [illegible]

[illegible] arm over the insulator. In [illegible]

referred to has therefore been used. Fig. 5 shows a mast with these slings and the clearances thereby obtained. As a matter of fact, however, on the majority of transmission lines where suspension insulators have been adopted no such refinement has been used for the purpose of maintaining this clearance, and it is evidently considered that trouble from this source is so unlikely as not to justify special provision to prevent it. This theory is largely justified by the fact that an arc would always tend to strike in the path of the strongest electrostatic field, which would generally be that over the insulator.

TENSION AND LOADING OF CONDUCTORS AND CONSEQUENT EFFECTS.

[illegible]—The Board of Trade Regulations assume the maximum conditions of loading to be a wind of 25 lb. per sq. ft. at a temperature of 22° F. without snow or ice on the conductors; and a factor of safety of 5 is required on the conductors under these conditions.

Other countries make different assumptions and stipulate other factors of safety. For instance, the U.S.A. Joint Report Recommendations assume a certain ice loading and a small wind. Nevertheless, ice does sometimes form on conductors in this country and high winds sometimes blow in the United States, and it is quite possible that the assumed conditions which occur regularly in one country may occur occasionally in the other. It is therefore instructive to make a comparison of the effect of such different assumed loadings upon the factors of safety in the event of a possible reversal of the assumptions.

For the purpose of making the necessary calculations the following case has been taken :—

[illegible]

[illegible]	[illegible]	Stress, lb.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Wind 25 lb. sq. ft. Min. temp. 22° F.	12,000	5	0·658	12,000	12,000	5
U.S.A. (Joint Report)	Wind 8 lb. sq. ft. Ice coating ½ in. Min. temp. 0° F.	30,000	2	1·05	18,700	17,800	3·37
[illegible]	Wind 11 lb. sq. ft. Ice coating ⅜ in. Min. temp. 32° F.	30,000	2	1·035	19,100	19,500	[illegible]

These figures show that the United States and Canadian factors of safety, compared on the same basis of loading as ours, are not so low as they seem to be, and in the assumed conditions under which we get our factor of safety of 5, they get a factor of safety in the neighbourhood of 3. As a matter of fact, the factor of safety of 3 is the one most favoured on the Continent, indeed by most countries. The factor of safety and assumed loadings have important effects on the efficient span length and on the cost of transmission-line construction, as shown later.

[illegible]

and in America and Canada as high as 700 ft. This is, of course, excluding abnormalities such as crossing valleys, rivers, and the like, which are common to all and require special treatment. One can design to get equal safety with any reasonable length of span, and economy should be the only consideration.

For the purpose of considering the relative cost of different spans a transmission line can be broadly divided into two parts, viz. (1) the conductors, the cost of which is practically irrespective of the span length, and (2) the supports, i.e. poles, insulators, and accessories, the cost of which will vary for different span lengths.

For practical purposes, therefore, it may be stated that the cost of different span lengths will vary according to the number of supports and the individual cost of such supports for such different span lengths respectively. For a given span the number of supports per unit distance is constant and the only variable is the cost of the individual supports. The cost of poles varies with the height and load. The height and load—and therefore also the cost and the economical span—vary with the size, tension, and loading of the conductor. The size, tension, and loading may be plotted as in curve A, Fig. 6, indicating the maximum sags and the loads for different spans.

Sags + fixed clearances, etc. = height of poles.
Loads × no. of conductors = load on the poles.

Heights and loads of poles may also be plotted as in Curve B, which indicates the cost (on a given basis) of poles of various sizes for different loads.

Cost of pole + cost of insulators,
cross-arms, and accessories = cost of the support.

There will, however, be main or angle supports, generally about one in eight, and the cost of these will be approximately double that of an ordinary support. Therefore

Cost of support × no. per mile + $\frac{1}{8}$ (no. per mile)
= cost of supports per mile.

The method of finding the theoretically economical span for any transmission line is therefore as follows:—

(1) Select any span and, knowing the size of conductor and the tension and loading to be allowed for, from Curve A find the sag and load.
(2) Take the sag and add the clearance, etc. This gives the height of the pole.
(3) Take the load per conductor and multiply it by the number of conductors and the factor of safety required on the poles. This gives the ultimate strength of poles.
(4) With the height and ultimate strength of the pole, from Curve B find the cost.
(5) Make an addition for insulators and accessories and multiply by the number of poles per mile, with an allowance for main and angle poles, and plot the figure obtained, as in Curve C.

This method will be readily followed by reference to the arrows on the curves.

By taking different spans and repeating the above procedure, a ◡ shaped curve will result, and the lowest point in this curve is of course the theoretically economical span for the particular conditions taken.

The set of curves, C1, C2, C3, and C4 in Fig. 6 for different sizes and different tensions and loadings of conductors have been plotted in this way, and the assumptions as to clearance, cost of insulators, etc., are indicated thereon. The cost figures are correct only for the basis prices as indicated, but it will be seen that the relative cost remains substantially correct irrespective of the basis price, and therefore the relationship between the economical values of different spans is equally correct. At any rate, the foregoing procedure and curves provide a definite basis to work upon and a nucleus upon which any refinements which occur to the user may be added.

Also it will be noticed that it is a theoretically economical span which is shown. This is a very necessary qualification, as the exigences of local conditions, such as the nature of the route, local prejudices, wayleaves, etc., may rule otherwise. Even then it will be something to work back from.

From the curves it at once appears that:—

(1) The larger the conductor the longer is the economical span, and vice versa.
(2) The higher the tension of stringing, the longer is the economical span, and vice versa.
(3) The larger the conductors the greater is the difference between the economical span lengths for U.S.A. and Great Britain conditions respectively (this is due to the ice loading on the U.S.A. conductors).
(4) The higher the tension of stringing the less is the cost of the transmission line.
(5) The greater the number of conductors the shorter is the economical span length.
(6) The economical span length is never shorter than 250 ft. for the cases taken.
(7) A wooden pole is impracticable for an ultimate strength of 24,000 lb. and over, whereas for ultimate strengths up to 6,000 lb. wooden poles have always the advantage over steel poles.
(8) Wooden poles are the more economical up to the points of divergence shown on the curves.

Span lengths of 600 to 700 ft. for U.S.A. and Canadian conditions are, in certain cases, shown to be justified. On the other hand, spans of 150 ft. appear never to be justified on economic grounds even with the low tensions of stringing used in this country. Similar calculations, however, show that the span of 150 ft. is correct in many cases with telegraph lines, and it may be that telegraph practice has influenced our span lengths in transmission-line construction.

Under Board of Trade requirements the cost of supports for spans of 150 ft. is shown to exceed the cost of supports for the economical span lengths by as much as £100 per mile.

Similarly for the economical span lengths the cost of supports under Board of Trade requirements is shown to exceed the cost of supports under Canadian and U.S.A. requirements by as much as £100 per mile.

Consequently, and as is also shown, the cost of supports for spans of 150 ft. under Board of Trade requirements exceeds the cost of supports for the economical span

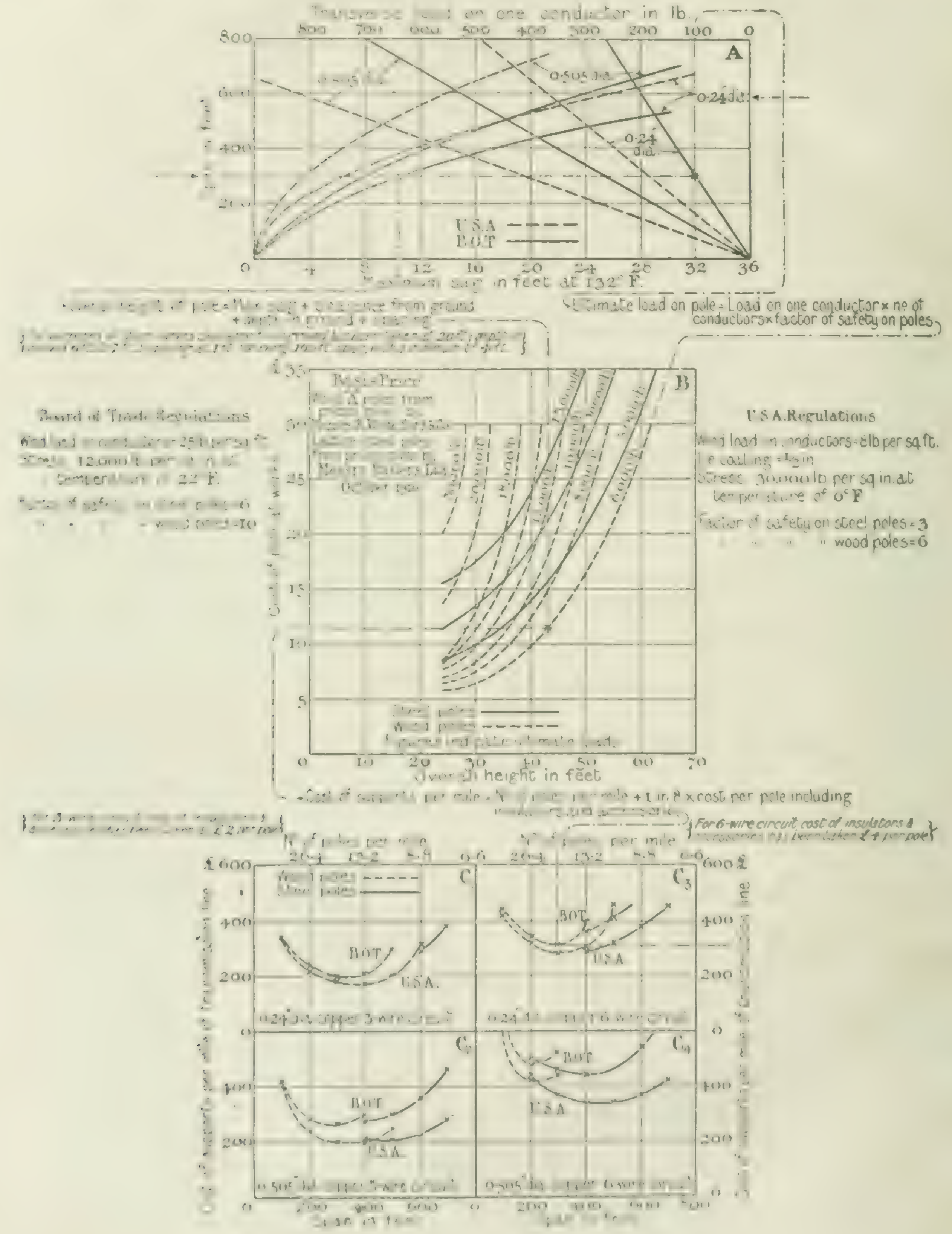
Transverse load on one conductor in lb.
800 700 600 500 400 300 200 100 0
A
0·505 dia.
0·24 dia.
U.S.A.
B.O.T.
Maximum sag in feet at 132° F.
0 4 8 12 16 20 24 28 32 36
Ultimate load on pole = Load on one conductor × no. of conductors × factor of safety on poles
+ depth in ground + spacing
B
Overall height in feet
0 10 20 30 40 50 60 70
5 10 15 20 25 30 35
Steel poles
Wood poles
Board of Trade Regulations
Wind load on conductors = 25 lb per sq ft.
Stress 12,000 lb per sq in. at temperature of 22° F.
Factor of safety on steel poles = 6
" " " " wood poles = 10
U.S.A. Regulations
Wind load on conductors = 8 lb per sq ft.
Ice coating = ½ in.
Stress 30,000 lb per sq in. at temperature of 0° F
Factor of safety on steel poles = 3
" " " " wood poles = 6
Cost of supports per mile = No. of poles per mile + 1 in 8 × cost per pole including
For 6-wire circuit cost of insulators & accessories has been taken £4 per pole
No. of poles per mile
20·4 13·2 8·8 6·6
£ 600 400 200 0
C₁ C₃ C₂ C₄
Wood poles
Steel poles
B.O.T.
U.S.A.
0·24" dia. copper 3-wire circuit
0·24" dia. copper 6-wire circuit
0·505" dia. copper 3-wire circuit
0·505" dia. copper 6-wire circuit
Span in feet
0 200 400 600 800

FIG. 6.

lengths under U.S.A. requirements by much as £200 per mile.

This is on the cost of supports delivered, but the cost of erection will be partly proportional to the number of poles and consequently to the span lengths, so that the abovementioned differences in cost when taken on such transmission lines completely erected will be greater.

Factors of safety.—From the foregoing curves it will be seen that it is expensive to obtain the factors of safety adopted in this country, especially on large conductors. Reverting to the schedule of assumed loads, it was shown that with the assumed conditions under which we get a factor of safety of 5, the United States get a factor of safety of 3·32. Consequently, under the ice conditions under which they get a factor of safety of 2, we should get a factor of safety of 3·06. This is, of course, on a 0·5 in. diam. conductor, but a further similar calculation shows that on a 0·2 in. diam. conductor we only get a factor of safety of 2·6.

Conditions not unlike this occur in this country,* and presumably the Board of Trade are satisfied with this factor of safety. That being so, it is difficult to see why what amounts to a higher factor of safety should be required for larger conductors. The factor of safety is of course most needed when the severest conditions occur, even if this only happens once a year or less often, and it would seem that, if any change were made, we could do with a higher factor of safety than that required by the Board of Trade Regulations for the smaller conductors, and a lower one for the larger. This is another way of saying that if we assumed the worst conditions, such as an ice load, a lower factor of safety could be used all round, which would give a higher margin of safety on small wires and an equal one on large. This would also tend to reduce the disproportion in the cost of transmission lines embodying conductors of average size or larger in this country compared with those elsewhere.

EARTH AND LIGHTNING WIRES.

The use of a wire or wires to maintain a uniform earth potential throughout the line is desirable. This wire is also employed for sundry other purposes, such as :—

(1) A catenary wire to carry an insulated pilot or telephone cable.
(2) A component of a protecting device against falling conductors, as in the case of the triangular guards.
(3) A mechanical stay to help to support certain types of flexible poles.
(4) A lightning shield.

All these uses are of more or less importance, but perhaps the most important and interesting function, particularly with long transmission lines in exposed positions, is that of shielding or screening the power wires from lightning and atmospheric disturbances. Atmospheric disturbances may manifest themselves in the transmission line either as a direct lightning stroke or as an induced charge, in either case setting up a surge in the wires. Earth wires will never completely protect the line, and consequently the insulators may still be called upon to withstand surges due to lightning; nevertheless, they provide a considerable amount of protection, as is substantiated by reports on the results obtained from their adoption in practice.

On transmission lines with the design of which the author has been concerned, earth wires have usually been adopted as lightning shields, and in common with most transmission lines they have always been of galvanized steel. The use of steel for these wires, particularly when placed above the conductors, has been deprecated* on the theory that owing to the shorter life of steel compared with, say, copper, such wires may break and by fouling the conductors interfere with the supply.

Having regard to the importance attached (and rightly so) to the flexible fixing of conductors so that they shall not break by crystallization, it is curious that a flexible support is never applied to earth wires; consequently the shorter life of steel earth wires may be made still shorter by crystallization.

Steel is much cheaper than copper or bronze, and before abandoning it in favour of more expensive metals its life might at least be made a maximum by fixing the wire with the same regard to crystallization as in the case of any other wire. A flexible clamp for this purpose is described later.

LOADS AT TERMINALS, ANGLES, AND INTERMEDIATE POSITIONS.

Terminal poles.—The poles upon which a transmission line terminates must deal with the maximum load due to the tension in the wires under the severest conditions of minimum temperature, maximum wind, and/or ice on the wires. Such load is, however, in the longitudinal direction, and the maximum load in the transverse direction is only that due to the wind on the wires under the worst conditions, which is generally very much less than in the longitudinal direction.

With wood poles the terminal pole is often designed for the transverse load and stayed in the longitudinal direction, this method dealing exactly with the stresses. Lattice-steel poles used as terminal poles are generally designed to carry the maximum load in the longitudinal direction without staying, and are almost invariably made of equal strength in both line and transverse directions—in other words there is a waste of strength in the transverse direction.

Angle poles.—A transmission line generally deviates from the straight at various points, thus necessitating poles to deal with these angles. The load on these angle poles will of course be the resultant of the maximum longitudinal loads due to the tension of the wires. There is, however, a point here which is not generally taken into consideration. The maximum tension can only come on the wires when the maximum wind is in a direction normal to the wires. The wind cannot be blowing in a direction normal to the wires in both the spans adjacent to the angle at the same time. Hence when calculating the resultant angle load it would appear that the longitudinal stress in the two adjacent spans should be taken, not as the maximum stress that can occur in each adjacent span individually, but as the maximum stress that can occur in each adjacent span simultaneously.

Intermediate poles.—At all points of the line other than terminals and angles, the stresses in the longitudinal direc-

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* C. VERNIER: Discussion on "British Practice in the Construction of High-tension Overhead Transmission Lines." *Journal I.E.E.*, 1914, vol. 52, p. 221.

* B. WELBOURN: *Journal I.E.E.*, 1914, vol. 52, p. 188.

[illegible] poles capable of dealing with the [illegible] capable of dealing with the transverse load due to wind on the wires. There is, however, a considerable divergence in practice as to the strength of such poles in the longitudinal direction. [illegible] channels, have practically no strength in the line direction, [illegible] A-pole [illegible] of about one-third that of the transverse direction, and some poles used abroad have equal strength in both directions.

The question is therefore what is the correct strength in the longitudinal direction for an intermediate pole. As the longitudinal stresses are balanced, theoretically there is no necessity for any strength. On the other hand, however, the poles have to be erected and conductors may break, so that in practice the poles require some strength. It is, however, generally considered that the breakage of one wire out of three, or two out of six, is the worst case that need be considered.

If pin insulators are used, the means of attachment to the insulators will generally permit of the conductors slipping (as shown later); and if suspension insulators are used, then the insulator string can swing out into the span, so that in the event of a break in either case the full tension in the conductor will not be transmitted to the support. Morever, almost any pole will deflect to some extent, which will further reduce the stress. In fact, the remaining load would not be much more than, say, equal to the transverse load in the conductor.

If provision be made for the breaking of one wire out of three, this would indicate that the intermediate poles should have a strength in the longitudinal direction of one-third that in the transverse direction. Thus in the remote event of all wires breaking, the load would still be within the strength of the poles by virtue of their factor of safety [illegible] ability to deflect. This is about the strength of the wooden **A**-pole upon which excellent results have been obtained, and in the author's opinion it provides a good basis of design for all intermediate poles.

Choice of Type of Insulator having regard to [illegible]

[illegible] or less long leverage. The proper function of pin insulators is therefore to support conductors [illegible] dealt with, e.g. on intermediate poles where the load is merely that due to the wind on the conductors. They may, however, also be used on small angles, the resultant [illegible] which transmit their load direct without leverage, such as [illegible]

[illegible], whilst sound mechanically, [illegible] voltages, owing to the fact that the upper and lower [illegible] Fig. 7 which shows pin and shackle insulators having comparable insulation). This is often lost sight of, with the consequence that the straining points of some lines have only about one-half the insulation of the remainder of such lines.

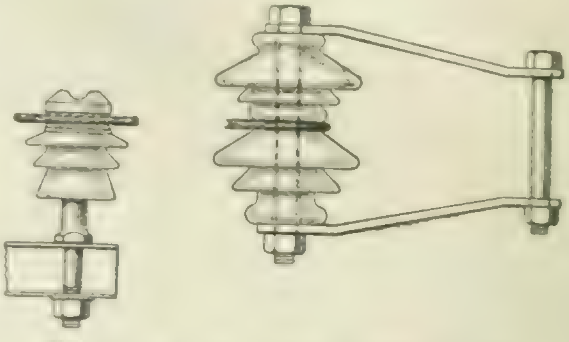


Fig. 7.—A pin and a shackle insulator of equal insulation.

Comparable insulation can, however, be readily obtained by the use of strain insulators of the disc type (see Fig. 8), which can be made up of one, two, or more discs as required; and this practice is rapidly superseding the use of shackles.

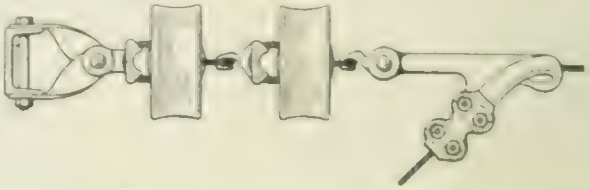
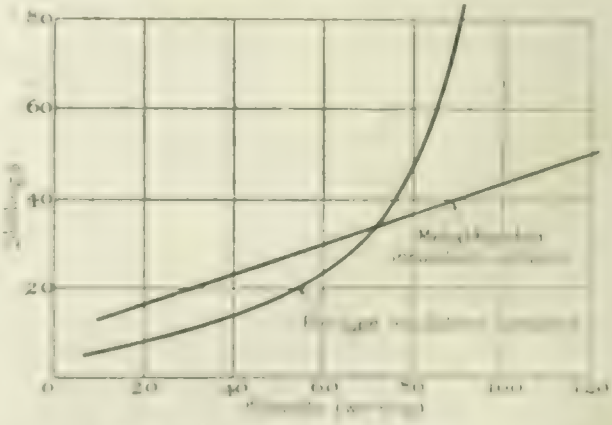


Fig. 8.—Strain insulator of disc type.

It is possible to design and manufacture pin insulators of sufficient size to give the tests usually required for a working pressure of 80,000 volts, but very little higher. Compared with suspension insulators, however, such



[illegible]

insulators are much weaker, both electrically and mechanically, and cost far more. This is shown in Fig. 9, which indicates that 66,000 volts is the economical limit for pin [illegible]

Suspension-type insulators mounted one above the other rigidly, thereby simulating the effect of a pin insulator, have sometimes been used for pressures above 60,000 volts. Such insulators, however, must necessarily put enormous bending moments in the cross-arms and it is difficult to see how this practice can be justified. This class of insulator has its proper use as a support for busbars, switches, etc., on the high-tension side of the generating station and substation.

Special Arrangements for Merz-Hunter Split-phase System.

The two conductors of each split phase are sometimes supported on separate insulators as if they belonged to separate circuits, but more often they are supported on the same insulator specially made with two side grooves. This necessitates insulators having specially deep heads, and whilst this is permissible with the smaller sizes, it is questionable with large sizes for the reason of expansion and contraction stresses referred to later.

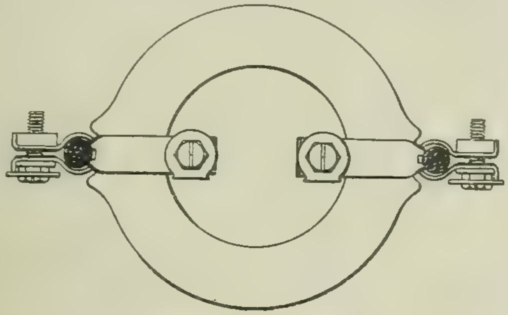


Fig. 10.—Spreader.

When suspension insulators are used, the split conductors are attached to reel insulators attached to the lowest unit. It is important to short-circuit the insulation of one of the reels or to make it of a conducting material, otherwise the effect is that of a small capacity in series with the larger capacity of the disc, and the reel may be in a state of continuous flash-over even at working voltage.

When the two conductors making one split conductor are mounted on one insulator it is necessary to provide insulating distance pieces, known as spreaders, in the span. The usual spacing of these is from about 30 to 40 ft., depending upon the size of, and tension of stringing the conductors. The form of spreader now largely adopted consists of a porcelain ring with two grooves in the periphery for the conductors, which are fastened thereto by means of small "stirrup" clips of copper (see Fig. 10). In view of the vibration the bolts and nuts are locked by a soft copper locking device which is pressed over the head of the bolt.

It is necessary that the two conductors making one split conductor should be strung with as nearly the same sag as possible, otherwise the result is unsightly, and the split conductors may "capsize," causing touching. It has been found difficult to obtain this exact adjustment of sag by ordinary means, and on some recent lines the strain insulators have therefore been provided with an adjusting device, as shown in Fig. 11.

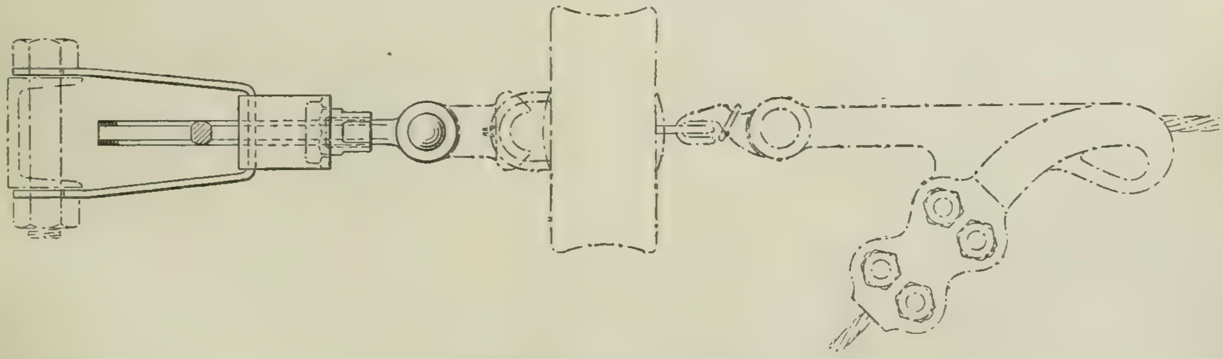


Fig. 11.– Strain insulator with adjusting device.

3. Particular Design of Transmission-line Material.

Poles.

Wooden poles.—The subject of wooden poles has been amply considered in papers read before the Institution and it requires little reference here.

It seems to be the general idea that wooden poles are not efficient for spans of more than 200 ft. or so, but the curves previously mentioned show that in some cases they can be used at their greatest efficiency for much longer spans.

Moreover, it has been considered that on pressure in the neighbourhood of 100 kilovolts, the length of the cross-arm necessary prevents the use of wooden poles. It is therefore of interest to note that one recent 100-kilovolt transmission line (the Montana Power Co., U.S.A.) is erected on wooden poles, the pole structure consisting of two 45-ft. wooden poles connected together by a single horizontal cross-arm from which the suspension insulators depend.

Tubular poles.—Poles made of single metal tubes are employed for telegraph and telephone lines and small electrical lines of the nature of overhead-distribution lines, but they are not as a rule economical at loads approaching those which come upon an important transmission line. Built-up structures using tubes for the main members have therefore been designed, but this class of structure does not appear to have been adopted to the same extent as wood or lattice steel.

There is, however, a special type of tubular pole, namely, [illegible] applied to transmission lines of the highest voltage. The facilities offered by this class of structure, particularly in [illegible] consideration, especially when a pole line has to be erected [illegible] ground or mountainous country.

[illegible] namely, narrow base structures and broad base structures.

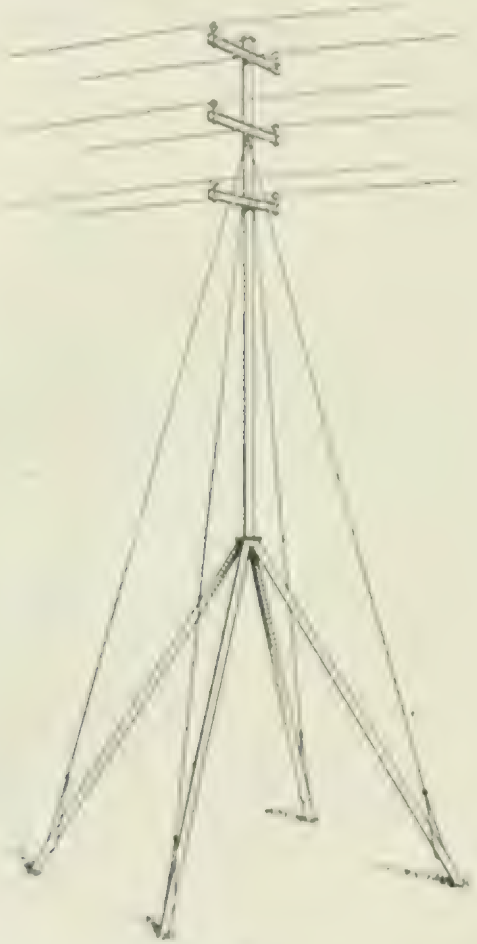


Fig. 12.—[illegible]

[illegible] mitted to the foundations by the lift on the one side and the thrust on the other side of the base, forming relatively [illegible] gned to transmit its load down to [illegible] members and thence to the ground. [illegible] slight movement and considerable [illegible] owing to this slight movement of the ground-line being resisted, causing failure of the bracings in the earth bay.

It is quite possible that something may inadvertently resist the movement at the ground-line or be deliberately placed there with the erroneous idea of strengthening the foundations; it would therefore seem to be sound practice to design the base members as for the assumed condition of the structure acting about the point A, which of course would require the introduction of a suitable strut at the ground-line C. This design of structure generally requires heavy corner members and very light bracings; in fact the load in the bracings is generally so small, and the bracings so short, that the smallest section permissible to hold the bolts and resist the weather is often much larger than necessary to deal with the loads. The design is therefore not as a rule very efficient and it is only justified where conditions of space prevent a broader base.

Broad base.—With this design of structure, owing to the wide spread, there is usually little horizontal reaction at the ground-line, and the base members, i.e. stub ends, have merely to take thrust and pull (see Fig. 13). This type lends itself to efficient design, but owing to the long lengths of bracings, etc., it is desirable that the ratio of the length to the radius of gyration for struts should be limited to a reasonable figure (say, 100 or so) otherwise a design which shows its full theoretical factor of safety may fail at a lower figure owing to the weakening of long struts by slight bends incurred in transit, or even due to sagging under their own weight.

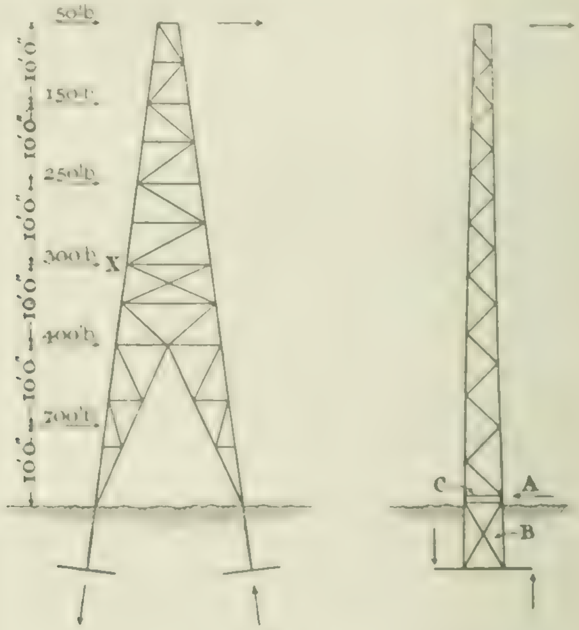


Fig. 13.

Tension members and struts.—It is usual practice with steel construction, including bridges, etc., to calculate factors of safety on struts on their crippling load, and on tension members on the ultimate strength of the steel, and such a mast would be considered to be correctly designed. There is, however, an important point here which affects the actual strength of a theoretically calculated structure.

With a strut under an increasing compression load, there is little change until it cripples, which it does quite suddenly, and it will develop its full theoretical factor of safety before crippling.

With a tension member under an increasing tension load, however, as soon as the elastic limit is reached it begins to stretch and the point of the structure which such tension member should hold is no longer held in the manner intended. Hence an entire redistribution of the stresses takes place throughout the structure, which consequently fails at a lower load than that calculated.

It would therefore appear that when designing structures such as lattice steel-work masts, as the factor of safety for struts is taken upon the crippling load, the factor of safety for tension members should be taken upon the elastic limit and not upon the ultimate strength.

Testing.—The usual practice is to test lattice steel-work poles by applying a pull at the top representing the load in the wires + the wind load on the pole itself equated to the top. One point, however, in regard to this practice of applying a load at the top to represent wind load, is that the wind load is naturally distributed over the structure, and the design of a mast to be correct must therefore deal with this wind load as its occurs.

Fig. 13 shows a mast with a wind pressure of 10 lb. per sq. ft. equally distributed over it. The wind load on the lower bays will obviously be greater than that on the upper. If we equate the wind load by taking moments round the base of the mast, we find that it equals a load of 740 lb. applied at the top. If, however, bending moments are taken round the point X, it is found that the designed bending moment at this point = 7,000 ft. lb., whereas the equated load of 740 lb. gives a moment at this point of 22,000 ft. lb., or over three times more than the structure at this point is designed for. Hence the mast similar to that shown in Fig. 13, tested with an equated wind load, failed at 25 per cent less than its designed load, and, as the lantern slide shows, failed in one of the higher bays (near the point X in Fig. 13), owing to such bays carrying not only their own load but the equated increment of the large bays below. To equate the wind load in this way for the purpose of test would therefore seem to be unfair to the structure.

Line Insulators.

A line insulator from the electrical point of view must be regarded as a more or less complicated electrostatic condenser with dielectric plates of porcelain (a material of high specific inductive capacity) and air (of low specific inductive capacity), the condenser plates being the conductor and its fastening, the pin or other attachment, and perhaps the layers of cement. All laws relating to condensers must be reasonably observed under what amounts to changing size and shape of the condenser plates due to rain, dirt, etc., and under frequencies ranging from normal to possible surge frequencies. At the same time the insulator must sustain more or less heavy mechanical stresses caused by outside loads and by inside stresses due to expansion and contraction under heat and cold of the different materials individually and relatively.

Electrical Design.

Up to comparatively recent times it was the practice to design insulators merely to give certain flash-over tests dry and wet, and with sufficient thickness to ensure that under test flash-over should occur before puncture. Considerable importance has also been attached to the leakage distance over the surface. It is obvious, however, that such figures are of little value as the surface resistance given by such leakage distance will vary with the width of the leakage path, which, of course, varies considerably with different sizes and shapes of insulators. Insulators have also been specially designed with extra long leakage paths to work in situations exposed to deposits of dust, salt, etc.

Such designs may be justified in the circumstances, but it would seem better to obtain the additional surface leakage distance required by using a correctly designed insulator of larger size than by altering a correct design to make it give a greater surface-leakage distance for the same size.

Ability to withstand a flash-over test without puncture is not necessarily a criterion of good design in an insulator, as an insulator of indifferent design may still give such tests. An indifferently designed insulator may have badly balanced shells and air spaces, causing some portions to be unduly stressed electrically. Under increasing test pressure the air contiguous to such over-stressed portions breaks down, i.e. becomes ionized and glows. Such ionized air being a conductor tends to increase the capacity of such portions and decreases the over-stressing, so that when the insulator is at its flashing-over point, it may be quite well balanced, not by its design but by the corrective balancing action of the ionized air. Air, however, takes a definite (though minute) period to ionize and a steep wave-front condition may not give time for the corrective balancing action of the ionized air; thus the over-stressed part may break down and result in the puncture of the entire insulator. It would seem, therefore, that an insulator should be designed for surges with steep wave front rather than for normal conditions. It is therefore desirable briefly to review the possible surges with a view to their effect upon the insulator and its design.

Surges.—As previously stated, earth-wires cannot be considered to be an infallible protection, and an insulator may still conceivably receive a direct stroke and may occasionally receive the impacts of surges induced by lightning. Lightning may directly strike an insulator and shatter it as by a mechanical blow[*] with or without electrical effects such as puncture or flash-over. Suspension insulators are, however, largely protected by the cross-arms, and pin insulators are generally somewhat protected by the poles or earthed metal-work projecting above them, so that an actual stroke on an insulator is fortunately not very frequent, and there is therefore no very great necessity to attempt to make actual provision against a stroke, which provision in any case seems impossible.

A lightning stroke though appearing to the eye to be one discharge, may be several separate discharges, each inducing in the wires a potential which may rise to almost any extent—only limited by the pressure necessary to arc

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[*] L. C. NICHOLSON: "A practical method of protecting insulators from lightning and power arc effects." *Transactions of the American Institute of Electrical Engineers*, 1910, vol. 29, p. 573

[illegible] and the rate of rise may be of [illegible] as, for instance, equal to that of a ¼ cycle of a frequency of a million per second. This will be manifested as a rapidly travelling wave with very steep front, which may be damped and dissipated in a comparatively small distance by the resistance of the line, augmented skin effect and corona, or it may reach the end of the line and be reflected back and set up oscillations of a frequency depending upon the capacity and induction of the line.

Switching and arcing surges may rise to a potential of twice the line voltage and will set up oscillations with a frequency depending upon the constants of the line, or, say, 1,000 to 5,000 periods per second, which indicates the steepness of the front; but whereas the switching surge may only continue long enough to permit of two or three wave-trains, the arcing surge may continue for much longer, depending upon how quickly the arc is suppressed.

One must therefore endeavour to design insulators having regard to these lightning surges with their steep front and high-frequency oscillations which may follow the lightning surge and which will be set up by switching and arcing. As already shown, poorly designed or badly balanced insulators may behave well under normal frequency owing to the automatic balancing action of the corona. Such an insulator under a steep wave-front condition, however, might puncture at a voltage even lower than its flash-over voltage under normal frequency. Hence the first requirement is to balance the parts of the insulator so that under steep wave-front conditions it does not depend upon corona to relieve the over-stressing. To obtain correct balancing the following considerations must be taken into account:—

The mutual capacity of the parts.

The concentration of flux upon a relatively small electrode, as, for instance, the pin. (This tends to increase the potential gradient on the shells near such small electrode.)

The capacity of parts to earth. (This increases the capacity current and hence the potential gradient on the shells nearest to the line.)

In addition to being balanced, the insulator should be proportioned to withstand the surges and oscillations of limited potential and frequency as set up by switching and arcing with an adequate margin against flash-over or puncture [illegible] when the almost unlimited rises of lightning surges occur, the insulator will be protected therefrom. This protection may be obtained by making use of the low dielectric strength of the air surrounding the insulator as a protecting gap or safety valve through which it may arc to earth and thus relieve the stress before damage can occur to the porcelain.

The thickness of porcelain must be determined with [illegible] and the shaping and [illegible], when the air gap breaks down, the arc will be thrown out from the shells so as to minimize damage by the heat of the arc. In proportioning the air gap and the thickness of porcelain, that which might be termed the "time lag" of the air gap [illegible] must be taken into consideration. [illegible]* have shown that under impulses of steep wave front the voltage required to break down air between spheres does not materially alter, but between needle points the air requires a higher voltage to break it down. The electrodes on a line insulator are certainly not of the character of spheres, and though they are not as sharp as needles, yet there will be an appreciable time lag.

To introduce spheres into the insulator design is feasible, but it is more practical to provide for the time lag by considering it as the extra voltage required to break down a given air gap, and to adjust the air gap and thickness of porcelain accordingly. In common with most insulation, the porcelain itself will withstand a greater voltage under a single impulse, but under a series of wave trains porcelain may break down by the cumulative effect of the continuation of the impulses. Hence, a lightning surge of very high potential is not necessarily the most severe condition, as it may only cause a single impact, whereas a surge of lesser potential setting up oscillations may do the most damage.

In regard to this cumulative damage, an impulse above a certain value would appear to break down the porcelain over a minute distance without breaking down the whole, just as the phenomena of corona breaks down a small amount of air without sparking across. With air, however, when the stress is removed, good air closes in on the fault, whereas with porcelain the fault remains and reduces the distance, thus increasing the gradient for the next impulse, which therefore extends the fault, and so on until complete rupture occurs. This is irrespective of the formation of heat by dielectric loss, but in indifferent materials containing occluded air and moisture the Joulean losses will add themselves to the dielectric loss, the combined effect of which will be considerable at high frequency. The latter consideration points to the necessity for the soundest possible porcelain.

All well-designed insulators will be recognized under test by the small amount of corona formation prior to flash-over.

Electrical design of pin-type insulators.—Pin-type insulators were first designed many years ago without great regard to the balance of dielectrics and their ability to withstand surges. These designs are generally tall, small headed, and elegant looking. If, however, these requirements are regarded, the resulting design becomes more squat and wide to obtain the protecting air path and free arcing characteristic, whilst maintaining electrostatic balance, and thicker in the head to obtain the puncture strength and reduce the flux. Consequently, such design is not so elegant, but, which is more important in engineering, is more efficient. It is, however, remarkable what good service the former designs have given, which is doubtless accounted for by the fact that such designs have been used on the lower pressures up to 30 kilovolts or so, for which voltages the electrical factors of safety are much higher. Insulators for the higher voltages, however, necessitate more accurate treatment.

Granted, therefore, that it is necessary to make adequate provision for correct balance and high frequency in insulators for the highest voltages, it is desirable for logical reasons, even though not so necessary, to apply the same principles to the designs for the lower voltages, even though they lose in appearance thereby. Fig. 14 shows

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Mr. F. W. Peek, Jun.'s investigations on this subject: [illegible]

* [illegible]

a comparison of the earlier design of insulator with an insulator primarily designed for balance and ability to withstand high frequency, and the comparative behaviour of these insulators under test is characteristic.

Electrical design of suspension insulators.—Suspension insulators are usually of one or other of two types, viz. the Hewlett or interlinked type, and the metal hooded or cemented type.

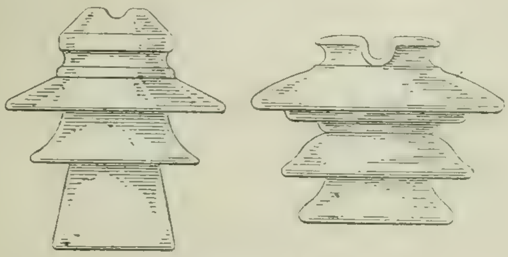

FIG. 14.—Comparison of insulators.

Hewlett type.—From the electrical standpoint the interlinking of the fittings causes a concentration of flux at the point where the interlinked fittings come closest together, i.e. at the point of crossing. Practice has proved, however, that provided the insulators are made of high-quality porcelain, as for instance English porcelain, they give satisfactory service. The insulators as supplied in this country are fitted with endless steel-wire grummets connected together by an **S**-shaped fitting devised by the author (see Fig. 15). The grummets are made on the insulator itself and then cemented in to prevent the wearing of either the porcelain or the grummet. The cement being hygroscopic also has the effect of what amounts to increasing the area of the electrodes and thereby reducing the flux density, and consequently improving the electrical characteristics of the insulator. As previously stated, this type of insulator is eminently suitable for use in conjunction with pin insulators on the straining points of the line. This design of insulator is also used on very high voltages, as, for instance, on the 88,000-volt lines of the Victoria Falls and Transvaal Power Co., and those made of sound porcelain, e.g. the English ones, have given good service. On the very high voltages, however, the metal-hooded insulator is more generally used, presumably owing to its better electrical characteristics.

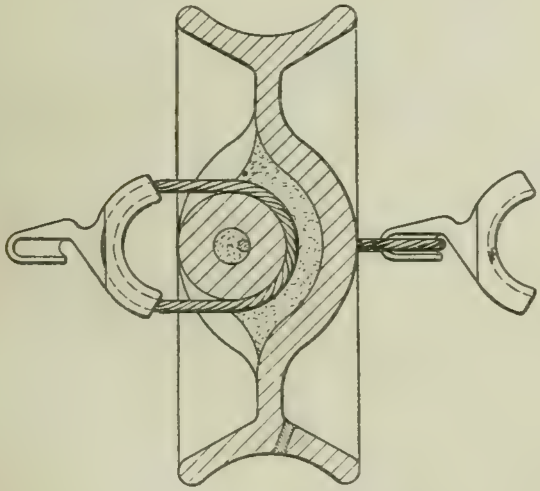

FIG. 15.—Hewlett type of insulator.

The Hewlett insulator as used for working in the horizontal position at straining positions has two flanges which cause it to have an excessively high flash-over voltage dry, which reduces the margin against puncture. As the result of experiments, the author has found a means of reducing the dry test by short-circuiting one flange in a position on the periphery opposite to the midway point between the two grummet holes (see Fig. 15). The position is important, otherwise the spray test is also reduced, which vitiates its use. The following are comparative tests with and without the short-circuiting of the flange or "over-pressure release."

Hewlett Insulators (Single 6 in. Disc).

	Ordinary without Over-pressure Release	With Over-pressure Release	Comparison with Usual Rating of Pin Insulator
	kilovolts	kilovolts	kilovolts
Working	6	6	6
Flash-over under spray	35	35	37
Flash-over dry ...	80	56	54
Puncture (uncertain)	80	80	80

Metal-hooded type.—The characteristic of the metal-hooded or cemented insulator is the concentric arrangement of the parts and the even distribution of flux which makes the insulator very good from the electrical point of view.

Considered individually, the suspension insulator is of very simple electrical design, but when arranged in a string in series, as for working at high voltages, some interesting features arise.

Distribution of potential.—That the distribution of potential along a string of suspension insulators is not equal is well known, but it is desirable briefly to refer to it here in order to lead up to other matters. Suspension insulators arranged as a string have a capacity to one another which might be called "series capacity," and a capacity to earth which might be called "shunt capacity." The unit nearest to the line has therefore to carry the "series capacity" current, which is uniform throughout the string, plus the "shunt capacity" current of the units above it. Each successive unit above has a lesser amount of "shunt capacity" current to carry. The voltage gradient will therefore be steepest on the line unit and less on each successive unit, the topmost unit nearest to the cross-arm having the least potential across it.* The unbalancing will be the greater the greater the ratio of shunt capacity to series capacity. Insulators therefore with large thicknesses of porcelain, such as a double piece or an extra

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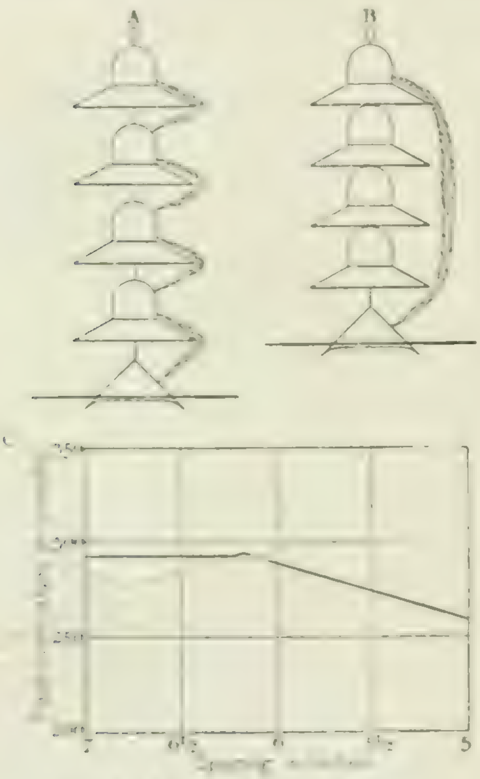
* As a matter of fact, the shunt capacity of one unit to another also enters into the question and tends to relieve the middle unit, whilst in combination with the capacity to earth it tends to make one of the units away from the cross-arm the least stressed; but the effect of this is slight and might be neglected here.

[illegible] considered individually, yet a string of them in series may have very bad characteristics.

[illegible] have a relatively low dielectric [illegible] Inversely, the better the porcelain the higher the capacity due to the material itself and the thinner it can be for a given strength. With English porcelain which has high dielectric strength, a 10 in. suspension disc, ¾ in. thick, has a flash-over value of 70 kilovolts, and a puncture strength of 156 kilovolts, and such a unit will give a much superior [illegible] 1 in. thick, particularly if of poorer porcelain. It will be [illegible] to get a thick dielectric, with the suspension insulator the [illegible] the case. With pin insulators, how- [illegible] (i.e. graded) to suit; whereas with suspension insulators the effect is greater, and though feasible it is not very practicable to grade the units to provide for this. The series capacity can, however, under certain conditions [illegible]



[illegible]

Effect of spacing on flash-over.—One effect of the uneven [illegible]

The ratio of these two figures has been called the "string efficiency ratio,"* and is an indication of the out-of-balance of the string. It is to be noted, however, that just as with pin insulators, the effect of corona is to increase the capacity of the most stressed shells or automatically to grade them, so that under test at normal frequency the string efficiency ratio may indicate a better potential balance than is actually the case under normal working voltage. If the units are spaced over a certain length apart, flash-over will take place between the metal-work of each unit (Fig. 16A), and further spacing apart will not materially alter the flash-over of the string. If, however, the spacing is reduced, the flash-over will take place over the entire string (Fig. 16B), and when this condition is first reached the flash-over of the string might be slightly increased due to the better flux distribution. The spacing can, however, be further reduced up to the limit of the minimum spacing required by the fittings, and if this is done, the flash-over will be decreased, thereby lowering the string efficiency ratio.

Fig. 16C shows the effect of these movements. The spacing of the units closer together will have the following effects:—

(1) The flux distribution will be better, due to the shortening of the path for such parts of the flux as pass through the air between the units.
(2) The arc will be thrown out from the porcelain instead of drawn in, and so will reduce the possibility of shattering the shells.
(3) The stresses on each unit will be reduced.

The latter reason is a very important one. Under pin insulators it was shown that it is desirable to reduce the air gap or increase the thickness of the porcelain. The necessity for not increasing the thickness of porcelain in the suspension-type insulator has been discussed, so that the only course open is to reduce the air gap and thereby the stress which can come on any unit including the line unit, and at the same time to reduce the time lag under high-frequency conditions. Yet that which provides the above important advantages and efficiency is stigmatized as bad efficiency, as judged by the string efficiency ratio.

The string efficiency ratio appears to be a reasonably accurate guide to the out-of-balance of a string up to the point of maximum flash-over for a given string, i.e. the knee on the curve; beyond that point, however, the string at least maintains its previous string efficiency, but gains in security by the reduction in potential which can come on to any unit.

This factor might be termed "string security factor"

$$= \frac{\text{maximum flash-over of string}}{\text{flash-over with reduced spacing}}$$

Under rain conditions the balance of the string is improved owing to the increase of series capacity due to the [illegible] current over such surfaces, which adds itself to the series capacity current. In consequence, after a certain number of units are added to the string, the flash-over under spray may become even greater than the dry.

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* [illegible]

Mechanical Design.

A line insulator, whether of the pin or suspension type, may be made up of one or more shells of porcelain with metal parts, usually malleable cast iron or mild steel, and in performing its normal function must encounter considerable variations of temperature. Expansion and contraction stresses may therefore occur even in one of the component materials owing to its uneven heating and cooling, and are bound to occur in the different component materials owing to their different coefficients of expansion. The problem is therefore to shape and proportion the various parts of the insulator so that these stresses are kept as low as possible and, in conjunction with the stresses set up by outside loads, well within those that the materials can continuously withstand without deterioration.

Metal parts do not generally fit in close contact with porcelain parts, nor do porcelain parts fit in close contact with other porcelain parts; there is always a layer of cement, generally neat Portland cement. Any stresses set up by the expansion and contraction of the parts will therefore be transmitted through such cement layers. Cement has, however, a low modulus of elasticity and a strength under compression very much less than either iron or porcelain, so that it will act to some extent as a cushion. From this point of view, the cement layers should be made reasonably thick. On the other hand, however, neat Portland cement, unless very sound, i.e. thoroughly burned and skilfully gauged, is liable to a slight expansion of its bulk, which may take several years to develop.

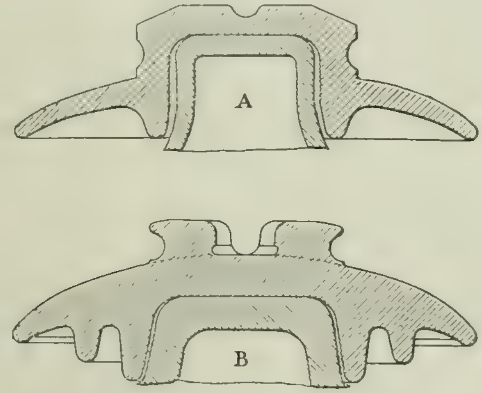

FIG. 17.—Large pin insulators.

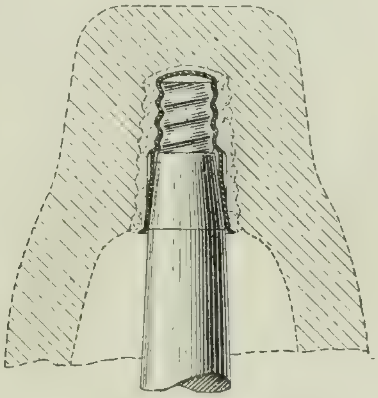

FIG. 18. Thimble.

It is also possible that such gradual expansion might be increased by some subtle chemical action causing crystalline growths, this chemical action being set up perhaps by the action of the electrostatic field on the air and moisture contained in the interstices of the cement. This latter theory is, however, very hypothetical, though the former is not, and in view of the effect of the human element in gauging and the probability of more or less imperfection of commercial grades of cement, it must be reckoned with. From this point of view the cement layers should be kept thin.

Between two parts, such as two shells of porcelain, which have the same coefficient of expansion, the desirable thin layer of cement can be used without corresponding disadvantage. When, however, there are solid and bulky metal parts, the expansion stresses will be appreciable and the cement layers must be of greater thickness so as to give the cushioning effect. In some cases, however, it is possible to keep such stresses low, thus avoiding the necessity of the thickest layers, as, for instance, by cementing a sheet metal thimble instead of a solid pin into a pin insulator. The stress may also be reduced by doing the work of cementing at a higher temperature, thus reducing the range of expansion, and also by the employment of other expedients. In any case, however, the cement should be chosen with care and gauged with skill, and the parts should be shaped so that whatever stresses may occur will not be localized.

Mechanical design of pin insulators.—A pin insulator may be heated to a considerable temperature by the sun shining directly upon it—probably more on one side than on the other—during which time the parts tend to expand; and it may then be subjected to a sudden downpour of rain, which suddenly cools the top shed, causing it to contract. With small pin insulators, nothing is likely to happen under these conditions. In large pin insulators, such as those for 50 kilovolts, designed with the top shell shaped as **A** in Fig. 17, considerable stresses may be set up at the corners, thus causing the side to split and fall off. This has been a source of trouble in America.*

It is, however, possible to design the top shed in the form of a continuous disc, with the head formed on the upper side and a flange on the underneath side for fixing to the other shells (see B in Fig. 17). The flange is given a slight slope and the cement space is kept thin, and as porcelain is a poor conductor of heat, this arrangement of head and flange largely obviates this trouble. It might be thought that this arrangement would weaken the insulator mechanically, but comparative tests which have been made show that the insulators so designed have a strength at least equal to that of earlier designs with the heads as shown in A, and have ample strength for any load which can (or ought to) come on them in practice.

As already set out, the characteristics of the design of a pin insulator limit its use to positions where the working loads are comparatively small, of the order of, say, 500 lb. [illegible] strength in a pin insulator [illegible] of the parts so as to suit best the electrical requirements and obtain freedom from stresses due to sudden extreme variations of temperature.

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* A. O. Austin: "Insulation Depreciation and Effect on Operation." *Transactions of the American Institute of Electrical Engineers*, 1914, vol. 33. p. 1731.

As the strength of the means of attachment, and also of the spindle, limits the stresses which can come upon a pin insulator, it would appear unnecessary to insist upon a strength in the pin insulator very much in excess of that of its spindle or of the means of attachment of the conductor, especially since, as shown above, the insistence on excessive mechanical strength merely obtains something of little or no value, at the sacrifice of something of real value.

Attachment of pin insulators to pins.—Many different methods have been employed for fixing pin insulators to spindles, including such devices as the Cordeaux screw, hemp fixing, cementing, or cementing in a separable metal thimble into which the spindle is screwed. The desirable fixing is a detachable one which permits of the insulators and spindles being transported and handled separately and of insulators being replaced. The Cordeaux screw and metal thimble both possess this advantage.

The Cordeaux screw fixing has been extensively used in this country, presumably because of its detachability, and also perhaps because it is inexpensive. The Cordeaux fixing, however, is certainly not good from an electrical point of view, owing to the presence of sharp edges and small air spaces between the metal and porcelain, and it is one of those liberties which may be, and therefore is, taken with insulators for comparatively small voltages, though it certainly ought not to be taken at the higher voltages. From a mechanical point of view the Cordeaux fixing is much weaker than any other.

Hemp fixing was presumably the outcome of the necessity for a method of fixing to certain foreign porcelain, a characteristic of which is its brittleness. With brittle porcelain the use of hemp may or may not be necessary, but with English porcelain—or American for that matter—which is tougher and more resilient, the use of hemp is not at all necessary. In any case, however, to make a good job of hemp fixing, the hemp should be wound on the spindle under tension on a lathe and screwed in on a lathe; and as such facilities are generally not available on the site, it has to be done at the maker's works. On the other hand, however, this increases the cost of carriage and the liability to breakage in transit, the extra expense of which, as shown above, does not appear to be [illegible]

The fixing of metal pins by cementing them direct into insulators makes a very sound job, but as the pins are of solid metal a good cushion of cement is necessary.

[illegible] applied to insulators of English porcelain fitted with metal-work cemented in, and it shows that when such fixing is properly done, no trouble occurs through expansion and contraction :—

> The insulator fitted with a thimble is immersed for [illegible] at [illegible] C. and is then [illegible] at [illegible] C. for [illegible] minutes. This test may be performed repeatedly without damage to the insulator or reduction of its electrical strength.

To ensure that the metal-work is correctly centralized and that proper materials are used, it is desirable that the cementing should be done at the maker's works, where these facilities exist. The same argument, however, as for hemp applies here, namely, that the cost of carriage and liability to breakage in transit cause extra expense. If, however, a separable metal thimble is cemented into an insulator, the advantages of proper centralization, materials, etc., are obtained, but the extra expense and risk of breakage in transit are obviated. Moreover, if the thimble is made in stamped sheet metal as opposed to a casting, the expansion stresses are kept low, and smaller clearances of cement can therefore be used.

A thimble of this nature is shown in Fig. 18. In this design of thimble the joint is made on a cone seat,* the screw in the upper half of the thimble being chiefly for the purpose of bringing the cone seats of the thimble and spindle into close contact. The cone-seated joint develops the full strength of the full section of the spindle, and the small taper of the cone, requiring at least a half turn to release properly, prevents looseness. This would appear to be one of the best methods of attaching an insulator to a pin.

Mechanical design of suspension insulators.—In suspension insulators porcelain and metal are in very close relationship and the insulators are also required to work under heavy loads, so that it is necessary to give very careful attention to the details of the design.

Metal-hooded insulators are sometimes considered to be in tension, and as porcelain is notoriously weak in tension the design is considered to be inferior to interlinked insulators in which the porcelain is in compression. The following test is therefore interesting :—

> Insulators A and B, Fig. 19, are identical as regards section of material, shaping, shear area of cement, etc., but the pin in A is inserted deeper than that in B.
>
> A gives an average strength of 4 tons and the porcelain is crushed without the cement being sheared.
>
> B gives an average strength of 2 tons and the spindle pulls out, shearing the cement.

It would appear that A transmits a large component of stress to the hood through the porcelain in compression, and the shape of the break as marked on the diagram and the stratified character of the porcelain at the break substantiates this.

Combined electrical and mechanical tests show that some designs fail electrically long before they appear to break mechanically, whilst others develop very nearly the full mechanical strength before electrical failure takes place. The former always appeared to be those where the shaping of parts indicated the possibility of severe and localized expansion stresses, and the latter where such stresses were likely to be the least and not localized. This shows that the design which gives the highest mechanical test is not necessarily the best design from the point of view of inside stresses.

A metal-hooded insulator may be designed for an ultimate strength of 10 tons or more. The same remarks that were made on this head under pin insulators, however, holds good here, as insistence upon unnecessarily high mechanical strengths precludes the easy shaping of parts which is so desirable for considerations of electrical soundness and freedom from expansion and contraction stresses.

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* Patent.

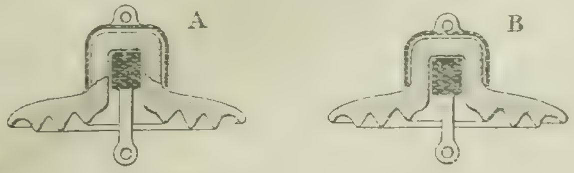

FIG. 10.—Metal-hooded insulators.

Transmission line conductors rarely have a breaking strength much in excess of $2\frac{1}{2}$ to 3 tons, and for such cases there would appear to be no object in requiring the suspension insulator to stand much more than this. For a load of 3 tons or so the insulator can embody the most desirable characteristics from every point of view, but for loads very much beyond this something has to be sacrificed.

TESTING OF INSULATORS.

The objects in view in testing high-tension insulators may be broadly classified as follows :—

(1) To detect insulators the material of which is faulty—this is generally termed a "routine test" and is applied to all material.

(2) To prove that a given design of insulator has the necessary margin of strength for the electrical and mechanical stresses which will be imposed upon it in practice. This is generally termed a "design test" and is applied to samples selected at random.

To these a further requirement might advantageously be added, namely—

(3) To ensure that material which withstands tests (1) and (2) and therefore is apparently free from faults in the new condition under which it is tested, will not sooner or later develop faults or deteriorate under the conditions of use. These might be called "deterioration tests," and might partly be applied to samples as a design test and partly to all material as a routine test.

The requirements of these different classes of tests need several different kinds of testing and combinations thereof.

(1) *Routine tests.*—These may be briefly summarized as follows :—

Electrical routine tests at normal frequency (50 to 100 ∿).

A predetermined voltage[*] is applied to each shell before assembly, and again to each assembled insulator for a period of 5 minutes, water generally being used as electrodes.

A high-frequency test as referred to later might also be applied in a manner to suit the requirements of a routine test.

Mechanical routine tests.—A predetermined mechanical load is applied to the insulator for a certain period of time, usually 10 seconds. The routine mechanical test is not as a rule applied to pin insulators, but with suspension insulators it is applied before the routine electrical test on the assembled insulator. Mechanical tests if taken to very high values may cause damage by starting internal cracks, and as the routine mechanical test is applied to insulators to be used on the line it should not be excessive and should be limited to about 25 per cent more than the maximum working load.

(2) *Design tests.*—An electrical design test at normal frequency (50 to 100 ∿).

For flash-over : the insulator is fitted with metal-work and is attached to a cross-arm as in practice, a gradually increasing voltage being then applied :—

(*a*) with the surface dry,
(*b*) with the surface wet by a precipitation of water at an angle of 45° to the vertical and at the rate of 1 inch in 5 minutes.

For puncture : the insulator with metal fittings as similar as possible to those used in practice, is immersed in oil and a gradually increasing voltage (at the rate of 10 kilovolts per second) is applied until puncture occurs.

The voltage on the high-tension side of the transformer used to be measured by means of a needle spark-gap. Needle points are, however, subject to variation due to brush discharge, etc., as mentioned by Mr. Lustgarten.[*]

The sphere gap is not subject to such variation when the spheres are of sufficient diameter in respect to the width of the gap to prevent corona preceding the spark. With a width of gap up to three times the diameter of the spheres there is very little corona, but for the most accurate work the width of the gap should not be greater than the diameter of the spheres. The sphere-gap readings are, of course, subject to correction for barometric pressure and temperature. A resistance which may consist of a porcelain tube filled with water should be placed in series with the gap to limit the flow of current at arc-over to one ampere or less, otherwise oscillations are set up, causing discrepancies in the readings, and the sphere gap may also be damaged through pitting.

The resistance of the water used for spray tests is important, and very different results are obtained with different qualities of water. Water with a resistance approximating to that of actual rain, i.e. distilled water, should therefore be used when especially accurate figures are required.

When insulators are submitted to design tests, the formation of corona on parts should be carefully observed, as much can be learnt in that way in regard to overstressing.

Electrical design tests at high frequency.—The term "high frequency" appears to be used rather widely, so as to include such different phenomena as :—

Continuous sine-wave high-frequency oscillations.
Damped high-frequency oscillations.
Impulses with a steep wave-front.

Continuous high-frequency or undamped oscillations are very severe on insulation, and there would appear to be no condition possible in practice which would be represented thereby.

These classes of high-frequency oscillations are hardly

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[*] This voltage should be in the neighbourhood of the flash-over voltage ; in fact, one English firm regulates the voltage so that the insulators flash over at the rate of as nearly as possible once per second. This makes the routine test very searching.

[*] J. LUSTGARTEN : "High-tension Porcelain Line Insulators." *Journal I.E.E.*, 1912, vol. 49, p. 235.

[illegible] commercial testing, but they may be of value in research work.

The [illegible] of a lightning surge of such a value as would break down the air surrounding an insulator might be represented by a single impulse test. As previously shown, however, a severer effect on an insulator results from a series of high-frequency waves. A high-frequency [illegible] may be set up by testing an insulator at [illegible] frequency at a higher voltage than the flash-over [illegible] sets up oscillations. This test can, of course, be applied without any additional apparatus other than the ordinary high-voltage testing transformer and is therefore simple, but on the other hand it is somewhat uncertain and indefinite.

The lightning surge-oscillation and switching or arcing surge-effects would appear therefore to be best simulated by high-frequency oscillations as given by a Tesla circuit. High-frequency oscillators * of this type have been made abroad, which, when taken off an ordinary supply at, say, 60 ~ per second give 120 trains of oscillations per second at a wave frequency of about 300,000 ~ per second. There are, of course, comparatively long periods of rest between each series of wave trains. The voltage is controlled on a control spark gap and measured on a sphere gap.

Insulators submitted to high-frequency oscillations should withstand the potential being increased until flash-over occurs without puncture. The severity of this test may be increased to any desired extent by maintaining such oscillations for given lengths of time, which is equivalent to submitting the insulators to a given number of wave trains at a potential either below the flash-over or any higher potential.

Mechanical design tests.—The insulator fitted with metal-work as in practice is submitted to a gradually increasing mechanical load until the ultimate mechanical strength is reached.

[illegible] As previously mentioned, in[illegible] electrical breakdown may occur in an insulator under mechanical test before visible mechanical failure occurs. This point can be detected by applying an electrical test to the insulator in conjunction with the mechanical test. This test would seem to be important, as an apparently high mechanical test is of no value if damage has occurred which causes electrical failure at a very much lower value. The best insulator from the mechanical point of view will be the one which will withstand, before electrical failure takes place, a load as high as possible in respect to the ultimate load.

3 *Deterioration test.*—It is important to recognize that [illegible] is not necessarily an infallible test of either the soundness of the material or the [illegible] might be quite [illegible] high-frequency tests, [illegible] conditions of changing temperature, [illegible], if the insulator be not properly [illegible] and thereby eventually [illegible]re. Moreover, an insulator slightly porous from [illegible] these tests when in a new and dry condition, but under working conditions such an [illegible] by breathing action set up by the changing temperature. It is probable that the so-called "fatigue" of insulators under high pressures has been due to these causes.

In regard to expansion and contraction stresses causing deterioration, the mechanical-electrical test previously referred to would, to some extent, detect this tendency, as an insulator in which these stresses are likely to be most severe would fail at a lower load. A more exact way, however, would be to perform this test with the insulator heated up to the maximum temperature likely to occur in practice.

In regard to the detection of slight porosity, probably the best way of discovering this is by the use of a "Megger" giving, say, 1,000 volts.

A test, presumably for the purpose of detecting porosity, and one frequently met with in specifications, requires that insulators be broken into small pieces and weighed after being kept in a warm, dry place for 24 hours, then soaked in water for 24 hours, the surfaces dried and again weighed, when no increase in weight must occur. The difficulty with this test is that it is impossible to remove all the moisture from the slightly rough surface of the broken pieces, so that if the balance is a very delicate one the pieces must weigh more, and if the balance is not very delicate then the test cannot be very valuable. A more searching way to discover porosity in broken pieces of insulators is to leave them to soak in a solution of analine dye and alcohol, and then to break the pieces transversely to the surface, when any absorption will at once be visible.

CONCLUDING REMARKS ON INSULATOR DESIGN AND TESTING.

The foregoing section on insulator designing and testing indicates that many considerations contribute to the design of an insulator which may be depended upon to give freedom from trouble in service. It has also been shown that indifferent porcelain is not only bad in itself but reacts against the design. However well designed an insulator may be, it will not make up for defective materials; and an indifferently designed insulator of good material will probably give better service than a well-designed insulator of bad material.

The desirable result, of course, is a combination of good material and good design; and as, especially with a material like porcelain, flaws are bound to occur occasionally in manufacture, careful and thorough testing is a necessity. The importance of sound material cannot be overestimated, and fortunately in English hard porcelain we possess a sound material which, in combination with good design, makes an insulator having exceptionally desirable characteristics.

As with most things, a carefully inspected and tested insulator of the best design and material costs more to produce than an insulator where refinements have been neglected. It is, for instance, quite easy to save 20 per cent or more on the design of an insulator and still give the same flash-over tests; and this saving can be increased if inspection and testing are not rigorously carried out. That such saving is not worth while will be granted when it is remembered that insulators only account for about 1 or 2 per cent of the cost of a power supply system, and that the power supply may be shut down by the failure of an insulator.

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* [illegible] *Transactions of the* [illegible]

Clamps or other Means of Attaching Conductors to Insulators.

The means of attachment of conductors to insulators should be such that:—

(*a*) Crystallization of the conductor must not be set up.
(*b*) The conductor should be held to the required load without bruising or injury to its surface.
(*c*) The attachment should be capable of being erected with ease.

The clamp or other means of attachment for fixing a conductor to a pin insulator must necessarily be different from that for fixing the conductor to a suspension insulator. Similarly, attachments to carry the dead end load must be different from those to carry the load in an intermediate position, but there is no reason why similar principles should not be reasonably embodied in all designs.

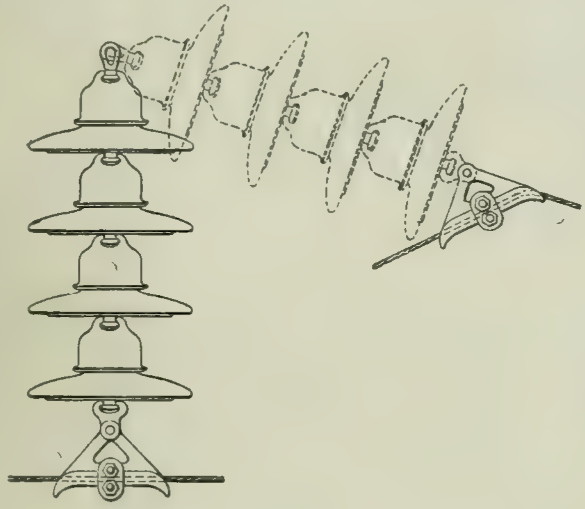


FIG. 20.

Clamps for strain insulators.—Strain-insulator clamps have flexibility to an eminent degree owing to all the motion being taken by the link attachment of the insulator, and they are therefore ideal from the point of view of the prevention of crystallization. A strain clamp necessarily requires a grip sufficient to develop the ultimate strength of the conductor before slipping. The best grip can be obtained by means of roughened gripping surfaces, but these injure the conductor and it is preferable that the gripping surface of the clamp should be smooth and rounded, which requires a greater length of surface than when roughened. In some forms of clamps this grip is obtained by gripping jaws consisting of two grooved plates bolted together. This, whilst providing an excellent grip, free from risk of damaging the conductor, is not the easiest to erect owing to the necessity of handling separate plates, bolts, and nuts whilst erecting.

For ease of erection, clamps providing the grip by means of hook bolts have been used, these bolts not having to be separated from the clamp during erection. Perhaps a better way, however, is to use plates bolted together as above mentioned, but with the bolt holes arranged so that the gripping jaws can be opened to receive the conductor without removing the bolts. A clamp on this principle is shown in Fig. 8. The eye at the end of the clamp enables a block and tackle to be attached to the clamp instead of to the cross-arm, thus facilitating the clamping-in of the conductor.

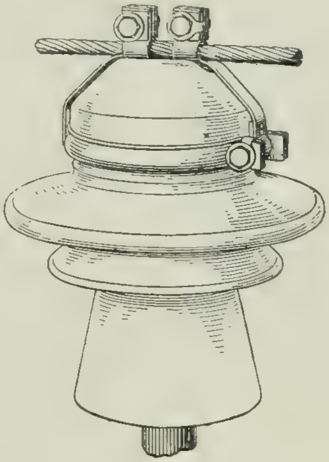


FIG. 21.—Stirrup clip.

Clamps for suspension insulators.—Suspension clamps have also a considerable degree of flexibility by virtue of being suspended from a link. In the event of a conductor breaking, the suspension clamp swings out into the line of the sag, thus reducing the stress, so that there is no necessity for the suspension clamp to grip the conductor to its breaking-point. In any case the intermediate pole upon which the suspension insulator is fixed is not designed to carry the stringing tension of the conductor. A light grip which will permit the conductor to slip at a load of 500 to 1,000 lb. is sufficient, and such a grip can be easily obtained in a manner which will not damage the surface of the cable.

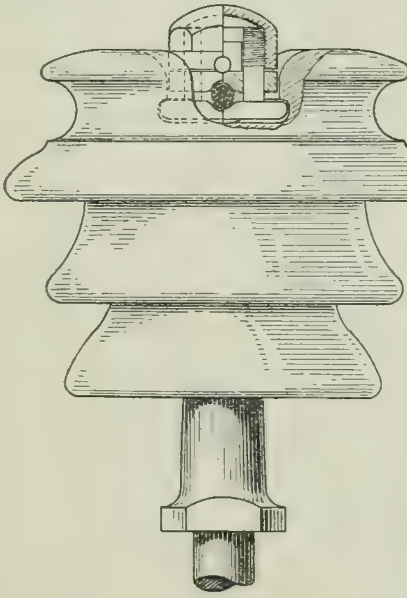


FIG. 22.—Flexible clamp.

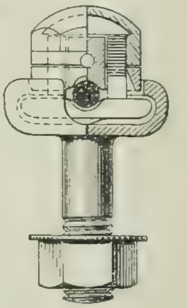


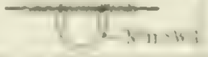
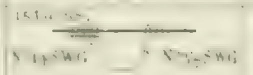
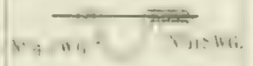
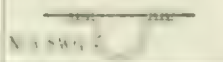
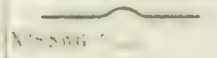
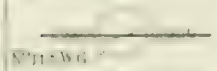
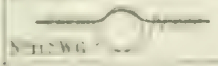
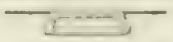
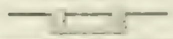
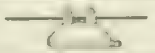
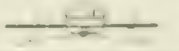
FIG. 23.—Clamp for earth wires.

The suspension-insulator clamp should have the ends [illegible] tion occurs [illegible] will not strike and shatter the porcelain of the last unit of the insulator chain (see Fig. 20).

Means of attachment for pin insulators.—The binder method of attaching conductors to pin insulators is largely favoured, particularly because of the amount of flexibility which it gives. The insulator groove which supports the conductor must, however, necessarily prevent to some extent the transmission of vibration; in other words, the binder method of attachment is not entirely flexible. [illegible] ticular shaping of this clamp gives a degree of flexibility sufficient to obviate crystallization, and it has given satisfactory service.

A new type of clamp [illegible] advantages of a mechanical attachment and yet be flexible is that shown in Fig. 22. This type of clamp has complete freedom of motion, and all wearing of the conductor by rubbing on the point of support is obviated.

Grip of pin-type insulator attachments.—Owing to the fact that a pin insulator is only capable of carrying loads of the order of the transverse load, there is no point in making the attachment grip to a greater load. The following results have been obtained from tests taken upon a range of different sorts of binders, clamps, etc. :—

FORM OF BINDER	DIAGRAM OF ATTACHMENT	SIZE & MATERIAL OF CONDUCTOR	PULL IN [illegible] DIRECTION SLIPPED AT LB.	PULL IN TRANSVERSE DIRECTION Load lb.	How failed
British practice		19/15 S.W.G. Cu	900	1,800	Binder broke
Locke's binders		6 S.W.G. Cu	335	1,400	Coils pulled out
		7/. Al	200	530	" " "
		7/. Al	130	1,900	" " "
U.S.A. practice		19/15½ Cu	200	300	Binder broke
		" "	100	600	" "
		" "	100	700	" "
Rigid clamp English		4/0 Cu	400	1,000	Insulator broke
American		19/13 Cu	600	1,800	Clamp distorted
"Stirrup clip"*		19/16 Cu	300	500	Clip distorted
Flexible clamp		19/15½ Cu	500-900 (according to tightness of grip)	1,900-2,400	According to strength of insulators

STRENGTH OF PIN INSULATORS AND PINS

Any pin insulator		Pull applied to conductor in top groove	If Cordeaux screw fixing 500-1000 lb. Any other fixing 1000-2400 lb. — Insulator either split longitudinally or head broke off
Forged steel spindles		Load applied at leverage equal to insulator top	If designed for 2000 lb. Permanent set starts at 1000 lb. If designed for 3000 lb. Permanent set starts at 1000 lb.

[illegible] shows, however, that this slight prevention of the transmission of vibration by the point of support is not harmful.

To attach the conductor to a pin insulator by a rigid [illegible] clamp is bad practice, as deterioration of the conductor by crystallization is likely to occur. To obtain a mechanical grip without rigidity the "stirrup clip"* shown in Fig. 21 was designed. The [illegible] and par- [illegible]

In no case does the means of attachment develop a grip anything like the strength of the conductor, but it lets the conductor slip at a load more of the order of a transverse load due to wind on the conductors. This is as it should be, otherwise the insulator pin or cross-arm would be damaged. The U.S.A. binders, however, seem to give too light a grip.

The flexible clamp shown in Fig. 22 has mechanical characteristics in both the line and longitudinal direction of the same order as a good binder and has a flexibility greater than any binder.

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* [illegible]

* Patent applied for.

In regard to ease of erection, a binder is probably always more difficult and requires greater skill to erect than a mechanical clamp, but of all mechanical clamps the flexible clamp shown in Fig. 22 is by far the easiest to erect, being merely dropped into the insulator head and turned at right angles, the conductor then being dropped into the slot and the one nut tightened up. This type of clamp is of course only suitable for use with the latest type of insulators (designed to withstand surges), the heads of which insulators are, as previously explained, formed on the upper side of a disc to avoid internal stresses.

Clamps for earth wires.—As previously mentioned, it would seem correct practice to attach earth wires to poles with due regard to flexibility. Fig. 23 shows a clamp on similar principles to the clamp for attaching conductors to pin insulators but arranged to take earth wires.

4. CONCLUSION.

The matter, data, and illustrations that have been referred to in the foregoing are almost exclusively concerned with transmission lines which have been engineered from this country, and the material for which has been designed and manufactured in this country.

In regard to the high-frequency tests and tests requiring pressures up to 500 kilovolts, reference has necessarily had to be made to those conducted by investigators fortunate enough to have access to such apparatus, but steps have been taken whereby the author will have the advantage of at least equally good facilities, when further data of a valuable nature is anticipated.

The author's best thanks are due to Messrs. Bullers, Ltd., for facilities afforded in connection with the preparation of the paper. He also wishes to acknowledge valuable assistance received from Mr. N. E. P. Harris in connection with the experiments, and from Mr. A. J. Cunningham in the preparation of data and illustrations.

DISCUSSION BEFORE THE INSTITUTION, 26 APRIL, 1917.

Mr. Trotter. Mr. A. P. **TROTTER**: Among the developments in electrical engineering which we hope to see after the War, overhead lines for bulk supply and for linking up will be an important feature. It is true that at present we have no higher pressure in this country than 30,000 volts, but I hope that we shall have in the future. For the limited lines that now exist, a considerable increase of voltage would so add to the terminal cost of the transformers, insulators, and switchboard, that the saving on the copper in the line would be swallowed up. We might calculate the critical point at which it is cheaper to send coal by train than to transmit electric power, having regard to the very peculiar conditions in normal times in this country with regard to the railways and the coal supply. It is wrong to make comparisons with countries which perhaps have no coal at all, or countries where no network of railways exists. It is very rare indeed that snow freezes on overhead wires in this country. In the past 10 years, which practically cover the experience of high-pressure overhead lines in this country, I cannot remember more than two or three cases in which snow binding on the wires has had any serious effect on electricity supply wires. Of course on Post Office wires it is altogether different. Passing to the question of factors of safety I find it stated on page 416 that there is a ratio of 5 to 2 between the factors of safety in this country and abroad. Is not that something like the ratio of the quality of engineering work in this country and abroad? I do not want to say anything against American work; they have their own methods to suit their own conditions. I think the ratio of the number of failures is even larger than the squares of those figures, i.e. 25 and 4, because in America a duplicate line is often installed alongside the first one. This is hardly ever done in this country as we expect the first line to stand. Of course the requirements are quite different. I am not criticizing American practice, but we know that most of the lines in this country are erected to ensure continuity of supply.

Reference is made in the second column on page 416 to the Board of Trade Regulations. I am not here to defend them, but it must be remembered how they arose. The first overhead wires were erected in Bond-street many years ago; and although, I believe, not a single accident happened, Parliament was frightened and thought that such wires would be put everywhere. They therefore passed legislation and handed the matter over to the Board of Trade, who passed the responsibility over to their Electrical Adviser. The Electrical Adviser has no one to consult and is not allowed to have an advisory committee. Is it therefore to be wondered at that factors of safety are rather high when the responsibility rests on the shoulders of one man to say "this is safe"? He is, I must say, very gratified when he finds that the engineers who use overhead wires are perfectly satisfied with the Regulations. Mr. Starr at the last meeting * said that he was quite satisfied, and in various papers read before the Institution the authors have said that they did not want any alteration in these factors of safety. It will generally be found that there is some proviso for the consent of the Board of Trade; that all the schemes must be submitted, considered on their merits, and passed. With regard to the 25 lb. per sq. ft. wind pressure, it must be remembered that after the Tay Bridge was blown down the Board of Trade standard wind pressure was 50 lb.; then it was reduced in the case of overhead wires to 35 lb., and now we have come down to 25 lb., but it is quite understood by those who erect wires that 25 lb. is the maximum. For a sheltered locality there have been several cases in which a lower wind pressure has been permitted; each case is judged on its merits. The rules in force in the United States and Canada are based upon accumulations of ice. We have not had occasion to make regulations for snow and ice in this country, and the Regulations distinctly state that no allowance has been made for them; that is to say, we expect that if snow and ice accumulate on the wires—which very rarely happens—the factor of safety will allow for it. These factors of safety are bound up with the question of responsibility. If I were a consulting engineer erecting a line over which

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* *Journal I.E.E.*, 1917, vol. 55, p. 348.

Mr [illegible] [illegible] I should have no hesitation in adopting [illegible] that the Board of Trade Regulations in a country where these Regulations [illegible]. These Regulations are made for the purpose [illegible] under the Act, mainly for a densely populated country and questions of public safety.

Now I should like to refer to the lengths of spans. It is suggested at the foot of the second column on page 416 [illegible] There is nothing in the Board of Trade Regulations limiting the span for high-pressure wires—those dealt with in [illegible] Regulations there [illegible]. The Regulations say [illegible] shall not be exceeded without the consent of the Board of Trade, which simply means that if one desires to have a longer span one sends in drawings and gives particulars and the application will then be considered. But what do we find in Canada? The author appears to [illegible]. Looking through the last Report of the Ontario Commission, I find that [illegible]. In this country a very common span for high-pressure wires is [illegible] Mr. Westinghouse's. That is the average span for ordinary cross-country work for the very moderate pressures to which we work. I repeat, there is no limit in the Board of Trade Regulations with regard to spans. As a matter of fact, there is a span of 1,420 ft. in South Wales and another of about quarter of a mile in North Wales. In the 1,420 ft. span no alteration has been made in regard to the type of tower used. Long spans greatly reduce the cost of wayleaves, as one is able to jump from hedge to hedge.

Mr. Dickinson. Mr. Alfred Dickinson: There are two or three things which I do not interpret in the same way Mr. Trotter does. For instance, it is my experience that voltage makes very little difference in the cost of transformers, at any rate of [illegible]. I do not agree with what Mr. Trotter has [illegible] high-tension work in this country. What are the Board of Trade Regulations made for? I understand that they are to protect the public. Having permitted a fatal voltage, I cannot see any difference, so far as injury or death is concerned, whether the voltage is 5,000 or 100,000. Permission to use high voltages would assist very much the development of long-distance transmission. (Mr. Trotter: There is no limit whatever to the voltage [illegible] in this country.) I think most of the members [illegible] Board of Trade [illegible]. I would suggest that when the Regulations are next under revision by the Board of Trade the new Regulations should be framed in conjunction with this Institution. My view is that the present Regulations [illegible]. I do not agree with Mr. Trotter that work should be done in a more slipshod way than [illegible] in this country, [illegible] British Colonies or in India. A point I wish to put for Mr. Trotter's [illegible] is that the various electrical authorities in the countries abroad under the British Crown take the Board of Trade Regulations as their standard, and they will not vary them. I could give instances where very [illegible] "These are the British Board of Trade Regulations and we cannot vary them." Mr If, when any new Board of Trade Regulations are framed, a short note could be added to the effect that they are put forward as a guidance, but that modifications are permitted to suit special conditions, it would help people who, like myself, are doing work in other countries. I agree with what the author says about tests. I have made the mistake. In future I shall simply satisfy myself that the particular type of apparatus will stand with the factor of safety desired, both mechanical and electrical, by testing samples, but I shall not subject each individual piece to the full test. I shall be content to test the bulk to 10 per cent above working load, and in that way I think better results in working will be obtained. First-class high-tension insulators can be made in this country, the very best material for the purpose being available. High-tension transmission is, in my opinion, only in its infancy in this country. I believe that in a short time a pressure of 100,000 volts or so will not frighten people. It is difficult to know what factor of safety to provide in the insulators on a transmission line. The author showed to-night an illustration of the special work at the creek crossing of the Tata hydro-electric transmission. In that location of the line the strong wind carries the salt spray on to the insulators. This calls for more insulator discs than are needed on the inland part of the line. No hard-and-fast general rule as to the factor of safety to be provided can be laid down; the line must be dealt with in sections. On some sections more discs are needed than on others. I know of a case where for a distance of 125 miles five discs are sufficient, whereas when the line approaches the coast eight are required. Insulators are subject to many strains not contemplated or provided for. About the second day after pressure was put on the Tata line a vulture flew against a slack telephone wire and carried it over the power line, thus breaking the wire long enough to permit the loose end to touch the earth as it swung to and fro. I should not like to suggest what stresses were set up in the line by the surges, but they were enormous. It is very difficult to build an insulator to meet these conditions. Although I have done it, I think it is wrong in a high-tension line to put the telephone circuit upon the same towers; many difficulties arise. On the other hand it is often difficult to run the telephone line apart from the transmission line because of the necessity of obtaining another right of way.

Sir W. Slingo. Sir W. Slingo: With regard to the question of span lengths, the author thinks that the 150 ft. span is a relic of telegraph experience. He is incorrect, because our heavy spans at the present day are 180 ft. long. When I speak of "heavy" I mean lines carrying up to 40, 50, or 60 wires of weights varying from 150 lb. to 600 or 800 lb. per mile. Ten or twenty years ago the spans were much longer, and the author can to-day see many of our spans which are 70, 80, 90, and 100 yards in length for mile after mile. It is only in very exceptional cases that we use these short spans of 150 ft. The question of ice to which Mr. Trotter has referred is, I think, important. I should like to give members the benefit of a little experience which was obtained more particularly in regard to the great storm on the 27th and 28th March, 1916, when over £300,000 of damage was done to the telegraph and telephone lines of the country as a result of snow and wind.

Sir W. Slingo.

I then found out that not a single wire weighing 600 lb. per mile (i.e. about 5½ S.W.G.) was broken down by the weight of snow and ice or the pressure of the wind. Wires of 400 lb. or more per mile in weight came down owing to either the poles or the arms being broken. I think that may be a point of some utility to power-transmission engineers, who I suppose never work with wires of a smaller gauge than that. There is one other interesting point in connection with wind pressure to which I should like to refer. Ice which is formed under peculiar climatic conditions—that is to say, which freezes as the rain falls—will sometimes form around the wire in a shape other than that of a cylindrical rod. In March 1916 there were many cases in which the ice took the form of a horizontal flat band, so that the wind pressure upon it was comparatively small. Another interesting fact that has been noticed is that the accumulations of snow and ice upon a wire are, generally speaking, independent of the gauge of the wire, that is to say, a thin wire will get as thick with snow as a thick wire. We come back to this point, therefore, that once we have our wires strong enough to withstand the wind pressure and the weight of the snow and ice which form upon them, then we can determine the minimum gauge of wire that we must erect in order to secure immunity from breakdown due to wind and snow. The Post Office started its work with copper conductors of 100 lb. weight and found that every small storm broke them down. That was 30 or more years ago. Then we went to 150 lb. as a minimum weight, and that stands up under all ordinary conditions; 200 lb. weight generally stands well; and 400 lb. and over will stand almost anything. I should be glad if the author would make some reference in his reply to his experience with regard to ferro-concrete poles. We have not tried any yet, mainly because they are very expensive and because we cannot readily do with them what we want, namely, put on 12, 16, or 20 arms. A pole that will carry one arm will suit the purpose of most traction engineers, but such a pole would not be suitable for telegraph work. So many conductors have to be fixed that the standardization of fittings would lead to considerable difficulties.

Mr. Jacob.

Mr. A. Jacob: I do not agree with Mr. Trotter that American and other long-distance power-transmission systems are unreliable; in fact, if an analysis were made of the leading modern transmission systems throughout the world, I believe it would be found that the failures on those systems were not appreciably more numerous than those in this country. I believe that Mr. Vernier stated in his recent paper* that there were some 2,000 miles of transmission in operation in this country, practically all of which is short-span work. This is but a very small figure compared with the transmission systems of the United States, Canada, Mexico, Scandinavia, Italy, or France. On hydro-electric transmission systems the power transmitted is generally greater and frequently more important than on the comparatively small installations in this country. There has not hitherto been any great need for long-distance transmission in England as the distances to be covered have been quite moderate. When we get power transmission from the coal-fields, and unrestricted wayleaves along the railways, I have no doubt we shall come to long-distance transmissions, and we shall then have to tackle the problem on an entirely different basis from that on which it is being dealt with at the present moment. Not only the engineering, but also the commercial side of the question has to be taken into consideration. The capital cost in any given installation of transmission and distribution is a very large proportion of the whole, and the cost increases very rapidly with increased factors of safety. Why, when a factor of safety of 3 is considered sufficient in countries where the weather conditions are, if anything, more extreme than here, is it necessary to have a factor of safety of 5 in England? What I suggest is that there should be a happy medium in this matter and that standards should be adopted after very careful consideration and analysis of existing practice throughout the world, and that the standards adopted should be international and not apply to Great Britain only. It appears to me that it is as much the business of the Institution as it is of the Board of Trade to frame such regulations. With regard to the question of revising the Board of Trade Regulations, I should like to call attention to those recently issued by Mr. Evan Parry, electrical engineer to the Government of New Zealand, which are the result of a vast amount of experiment and study and are most practical and worthy of close attention. The other point with which I should like to deal is the question of conductors. The author has practically ignored the existence of any other conductor than copper. That is probably due to the fact that the only competitor in peace time is aluminium, the output of which is at present exclusively reserved for munitions. In Central Europe, the famine of copper and aluminium has led to the substitution of other metals for both bare and insulated cables, more particularly iron, steel, and zinc, and very comprehensive regulations and standards have been issued by the Verband Deutscher Elektrotechniker governing the use of such substitutes. In view of the anticipated continued scarcity of copper after the War, owing to the enormous demands for the metal for replacing that taken from industry and households to make munitions, the Germans are now considering more permanent substitutes and are standardizing the use of aluminium, not only for bare and insulated cables, but for windings of electrical machinery and transformers, for switchgear, and many other purposes. I suggest that the V.D.E. Regulations governing overhead transmission-line material merit careful study by the members of this Institution. The latest development in the use of aluminium is a steel-core strand, which eliminates many of the early troubles with aluminium due to increased sag. The world's longest transmission system, that from Bishop's Creek to El Centro in California, a distance of 404 miles at 15,000 volts pressure, employs such a steel-core strand with an average pole spacing of some 650 ft. The following figures show the superiority in mechanical characteristics of steel-

	Aluminium	Aluminium-steel	Copper
Weight for equal conductivity	1·00	1·61	2·19
Diam. " "	1·00	1·13	0·78
Strength " "	1·00	2·17	1·38

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* *Journal I.E.E.*, 1917, vol. 55, p. 329.

[illegible] all [illegible] [illegible] [illegible] [illegible] than for pure aluminium, but very much less than for [illegible] [illegible] [illegible] [illegible] have been in service for a number [illegible] such a variety of localities and under such [illegible] that their efficiency and reliability have been thoroughly demonstrated. The lantern slide shows a method of catenary suspension where the supporting [illegible] aluminium cable, the suspended contact wire in this case [illegible] ment of feeder and catenary and it has been adopted on the Canadian Northern Railway for a line recently [illegible] raised by Mr. Mordey as to ice and snow on aluminium conductors, authorities appear to be agreed that they do not collect to anything like the extent on aluminium as on copper. Mr. H. W. Buck, in a paper read before the St. Louis Congress in 1904, stated that "Aluminium wire [illegible] much less sleet than copper. This is perhaps [illegible] to the grease which is absorbed due to its porous [illegible], in the process of wire-drawing."

Mr. Highfield. **Mr. J. S. Highfield**: I should like to support what Mr. Trotter said about the desirability of working for [illegible] perhaps the tendency in this country has been to aim for too great security, but on the whole it has been both for the benefit of the public and particularly for the operating engineer. I [illegible] power [illegible], as we hope and believe they will do, the [illegible] reliability of supply will become increasingly [illegible] so that I hope engineers in the future will not [illegible] to decrease that security. In general the [illegible] is this. If we adopt the greatest security, the initial cost of the whole installation is necessarily high, but on the other hand the annual charges for maintenance are low. If we add together the interest on the capital and the annual charges for repairs and maintenance, it will be found [illegible] very nearly the same in both cases, so that [illegible] work, there are [illegible] where a minimum sum only can be [illegible] be quite prohibitive. In such schemes risks must be [illegible] better to have an inexpensive [illegible] the future [illegible] carried out [illegible] two standards would be of [illegible] the conductors [illegible] keeping the cross-arms as short as possible. With that arrangement it is necessary at given distances to cross the phases over so as to keep them balanced; a very simple wire system is all that is necessary, and there is a good deal to be said for such a simple arrangement. In using steel poles, particularly in damp and warm climates, it is very necessary to take great care to protect the metal-work from corrosion; and in using tubular poles it is particularly necessary to see that the whole of the inside of the pole is coated, otherwise destruction, once it starts, will go on very rapidly. It is not so easy to paint the inside of a pole as one might think. Poles are dipped before they are sent out from the works, but during transit and in course of erection the paint gets displaced, and by the time the pole is completely erected a considerable part of the inside is not painted. The Cornwall Power Company's engineers developed quite a good way of overcoming the difficulty. A hole was made in the bottom of the pole, which was pumped quite full of paint; then the paint was run out and a perfect coat of paint remained over the whole of the inside. It is not quite so easy as it sounds, because there are leaks all the way up in the tie bars and the joints. It is necessary to blow the paint in suddenly, and to do that two tanks were used, one containing paint and the other containing air under pressure. By opening a cock between the two tanks the paint could be projected suddenly to the top of the pole; by releasing the pressure equally quickly the paint came back into the tank. In this way the leakage was reduced to a minimum owing to the short time the pole was full of paint. Steel poles possess one great advantage over wooden poles in the great length of span that can be adopted. There is no difficulty in using at least a 400-ft. span with them. That is particularly necessary in a country like England where difficulty is experienced not only in getting wayleaves but in finding places in which to put the poles when one has obtained the wayleaves. A farmer does not like a pole placed in the middle of a field; he likes it placed in the hedgerow or where it is not in the way. Therefore there is an immense advantage in being able to work with very long spans. I should very much like to support what Mr. Dickinson said about testing. I am quite certain that to test a line to an excessive pressure is a great mistake. It only causes trouble. I think it is much better to make quite certain that all the gear is good by a severe test, and then put it all up and trust to the ordinary course of working to find out the defects, which will very quickly be done. It will be found each year after a line has been erected that insulators fail, and, as a rule, the earlier years always show more failures than the later. In other words, in the [illegible] pressure which necessarily occur seek out the defective insulators.

Mr. [illegible] **Mr. A. E. W. [illegible]**: [illegible] made for the temperature at which the strongest winds may be expected in each particular locality. Mr. Welbourn, in a paper read before the Institution in 1914,* after giving the formula to ascertain the maximum angle to which

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* [illegible]

Mr. Richards.

wires might swing, recommended that they should be spaced at a minimum distance equal to their sag at 60° F. That, I think, is a very sound practice, and it appears to correspond approximately to the author's curve for the smaller wires, 0·24 in. diameter. Does the author consider 60° F. the correct temperature to assume for this purpose in England? I should also like to ask him how he has arrived at the temperature of 132° F. (given in the top curve on page 418) as the maximum obtained in the sun in this country. Failing to find any authorized figure, I generally take 122° F. solely because that is the point at which calculations are easiest to make, since we necessarily have to find the sag at 22° F. as a basis. It would be an advantage to have a definite ruling by the Board of Trade on this point, as it governs the length of poles. Strictly speaking, of course, the sag due to load on the conductor should be added to that due to external temperature. The statement is made on page 417 that "from the curves it at once appears that the larger the conductor the longer is the economical span," but I do not think the author's curves on page 418 bear this out. Though at first sight the statement may appear true for steel poles, the curves show clearly that the contrary is the case for wooden poles, e.g. the most economical span for three small wires is shown to be about 300 ft., and for the larger size about 200 ft. Further, the author has not taken into account maintenance and life, and I think it is generally agreed that in these respects wooden poles can show an enormous advantage over steel in this country.

Mr. Wigham.

Mr. J. C. WIGHAM: I have been particularly interested in the curves which show the most economical transmission line of steel and alternatively of wood poles under the Board of Trade Regulations, giving for steel approximately a 400 ft. span, and for wood 200 ft. Those are the same as we arrived at in practice. These curves show that even with the U.S.A. Regulations 400 ft. is the economic span for a heavy wire. What is the advantage of the enormous towers shown in Fig. 1? If the author's curves are correct, why are such heavy transmission poles and long spans adopted so much abroad? One point which is borne out by the paper, and which is not generally appreciated, is that the factor of safety with small wires must be a great deal higher than where large wires are used. That is why the Post Office wires come down in a snowstorm and the electric power lines do not.

Mr. Mordey

Mr. W. M. MORDEY: It would be useful if in this discussion we could clear up the question of the difference between copper and aluminium overhead conductors as regards the deposit of snow or ice on them. Mr. Jacob in a previous discussion quoted extensive experiences in Norway, showing that so long as the aluminium lines are alive, there is nothing but hoar frost on them. There have been opportunities this winter of obtaining information on this subject.[*] The only other point I desire to mention is a method which I have used for testing insulators. I partly immersed them inverted in trays of very slightly acidulated water, putting some water also into the hollow of each insulator. They were run for many hours with a little piece of copper wire hanging in each cup as an anode on a 2,000-volt continuous-current circuit. This generally produced in a small proportion of the cups a slightly blue coloration, showing that a small current had passed, enough to colour the liquid with a copper salt. In that way insulators were weeded out which appeared by ordinary tests to be perfectly good. Whether they would have broken down on the line sooner than the others, I do not know.

Mr. Spark

Mr. C. P. SPARKS: I had some early experience of overhead transmission and therefore heard with interest the remarks by Mr. Trotter and Mr. Highfield in regard to Bond-street. I was assistant to Mr. Ferranti over 30 years ago when overhead wires were first erected in London for electricity supply. Why were they used? At that time if cables were put underground the undertaking was purchasable after 21 years. We were obliged therefore to put the lines overhead. For the safety of the public, insulated wires were used, but it was soon found safe to operate with bare wires. The wires were not only erected in Bond-street but extended in the direction of the City, Hampstead, and Kensington, and quite a comprehensive scheme was worked out by Mr. Ferranti. He was not satisfied with what was then thought to be the high pressure of 2,500 volts, and we were putting up overhead bare lines to operate at 10,000 volts when legislation was passed giving us a franchise for 42 years. That is what stopped the erection of overhead wires in London. I should like to show on the screen some views of an overhead line with which I have been concerned in South Wales. I read a paper before the Institution a little more than two years ago on "Electricity Applied to Mining,"[*] in which I mentioned that the Powell Duffryn Steam Coal Company were erecting over the Welsh hills an interconnecting line between 9 and 10 miles long to operate at 30,000 volts. I believe that is one of the lines to which Mr. Trotter alluded, and it came into service in October last. This overhead line connects the collieries in the

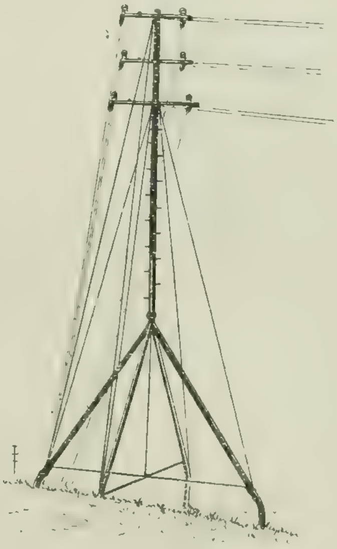

FIG. A.—Angle pole.

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[*] *Added later.*—See discussion on Mr. Welbourn's paper, *Journal I.E.E.*, 1914, vol. 52, pp. 222–3. Resulting from that discussion, Mr. W. B. Woodhouse put up experimental copper and aluminium conductors for observation. He now writes to me as follows:—"The observations we have been able to make have not been at all conclusive. Up to the present I can only say we have noticed no difference."

[*] *Journal I.E.E.*, 1915, vol. 53, p. 389.

Mr. [illegible] [illegible] live-steam turbo-alternators, the others, in order to utilize the waste heat from coke ovens, with gas engines and also [illegible] [illegible]ar was 75 million units. The line is [illegible]ted for a working pressure of 30,000 volts and is [illegible] [illegible]ers. The line constructed on the Merz-Hunter [illegible] stranded copper conductors, the phases being 5 ft. apart [illegible] 4 ft. horizontal centres. The conductors are carried on pin-type insulators mounted on three channel irons, the latter being protected by insulated sleeves to prevent birds [illegible] [illegible] Fig. A) with lattice masts in special locations

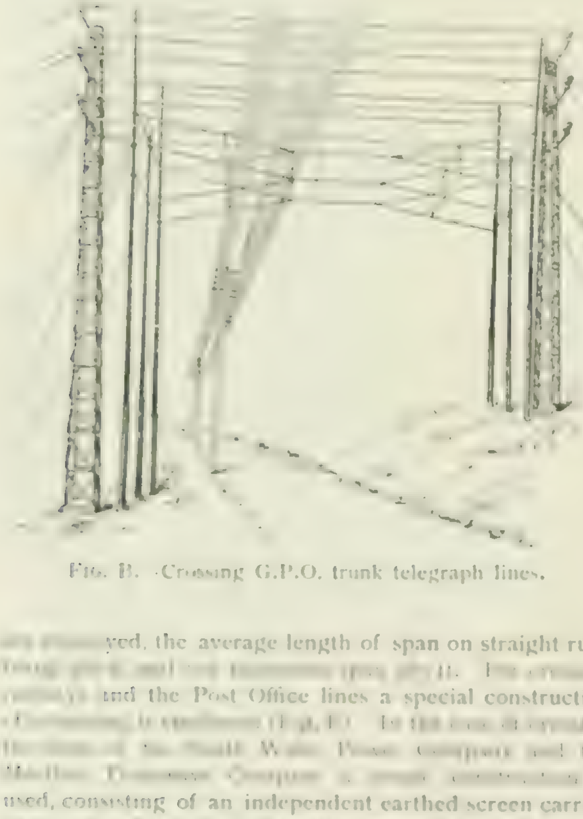

Fig. B.—Crossing G.P.O. trunk telegraph lines.

[illegible]yed, the average length of span on straight runs [illegible] [illegible] and the Post Office lines a special construction [illegible] [illegible] used, consisting of an independent earthed screen carried [illegible] 7/13 S.W.G., is carried on a flexible clip fixed below the [illegible] [illegible]re of the line. For the substation con[illegible]

[illegible] down any excess pressure waves. Mr. S[illegible]

Mr. J. W. Astley (*communicated*): The advisability or otherwise of placing an unyielding substance at the base of the mast depends of course on the nature of the soil to which the stresses have to be transmitted and the extent to which movement must be limited in order to retain alignment. The horizontal pressures at the foundation may be reduced by increasing the depth of structure below ground-level. Therefore, if movement takes place at ground-level the point of reaction automatically falls to a lower level until it reaches an unyielding substance which will support it. The distance between the reaction at ground-level and the root of the pole being reduced, their values are increased. Therefore, contrary to the author's statements, it appears to be desirable to limit the horizontal movement of the structure at the ground-line to that which takes place when the foundation beds itself on the first application of the load. The case of failure which is attributed to this movement at the ground-line being resisted could more reasonably be said to be due to the inability of the bracing to withstand the greater shearing stress below ground-level, but it is hardly conceivable that with a concrete foundation a failure such as that indicated would occur, as the bracings would then be relieved of the excessive shearing action. For equal heights and loads it is quite probable that up to a certain height the narrow-base structure is more efficient than the wide-base structure, when reckoned in terms of cost. When erecting insulators of the Cordeaux screw type, I have often screwed on the insulator with a lap of spun hemp in the threads, and all the insulators I have erected in this manner are quite satisfactory. My firm has, however, carried the idea of hemp attachment to a very high state of perfection. The method of accomplishing this is somewhat as follows :—The thread within the insulator is screwed six threads per inch and the stalk is screwed to the same pitch, but its external diameter is made slightly less than the internal diameter of the hole in the porcelain. A hole is provided in the spindle at the bottom of the "V" of the end thread for cord attachment. Hard tarred hemp of approximately 3/16 in. diameter is fitted into the hole and then wound around the spindle into the "V" of the thread. The spindle is then wound into the insulator, the hemp acting as the male thread.* By this method the hemp is forced into "V's" between the internal and external threads and becomes very solid. Tests conducted on insulators of a small type fitted in this manner broke down at a mechanical stress of 6,500 lb., and examination showed that the hemp in the unbroken porcelain was still quite firm. Experiments with hemp applied in this manner have gone to show that the hemp can be arranged to give equal results to the tensile strength of the metal employed. Fig. C herewith illustrates the method of applying the hemp to the Cordeaux type insulator. The author points out that under certain tests no trouble occurs through expansion and contraction, and cites a method of conducting such a test. I hardly think that the test is correct for the working conditions which have to be fulfilled. Messrs. [illegible] Creighton and P. E. Hosegood of the consulting engineering department of Mr. Astley

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* [illegible]

Mr. Astley.

the General Electric Company, U.S.A., in an article in the *General Electric Review* for June 1916, point out that the majority of failures of insulators on transmission lines have been due to two causes, viz. cracks and porosity. They state that "the cracked porcelain is due primarily to the unequal expansion of metal and porcelain coming from the fact that the iron has a coefficient of expansion about twice as great as porcelain. This trouble does not show up during the early months of use of the porcelain because the Portland cement has not yet hardened sufficiently to transmit the strains." It was to combat this trouble and to provide a ready means of renewing a damaged insulator that this tarred hemp method of attachment was introduced. The method is shown more clearly in Fig. D. I might add that there is no difficulty in obtaining the required mechanical strength, and the resilience of the tarred hemp is sufficient to provide for the coefficient of expansion in any climate.

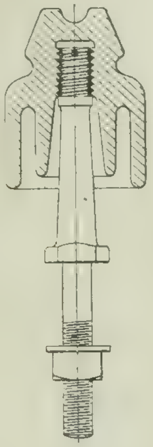

FIG. C.—Cordeaux type.

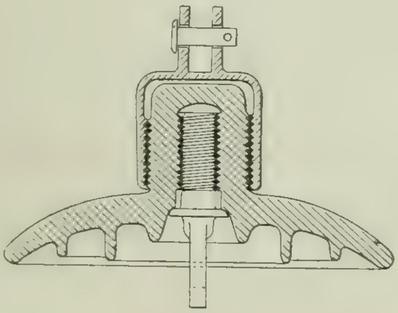

FIG. D.—Suspension type.

Mr. Blakemore.

Mr. E. BLAKEMORE (*communicated*): From the introduction to the paper it would appear that the author is urging English engineers to exert themselves to take up foreign trade relating to transmission of electric power, and with this end in view it would be of great interest if he would give us some information on the following points:—(*a*) Rights of way, etc., in various countries. (*b*) Life of various woods when used for poles in different climates. (*c*) Maximum fall of rain, pressure of wind, etc., in various countries. (*d*) Method of maintaining a good earth along the pole line in tropical countries. (*e*) Would a shorter pole decrease lightning effects on lines in the tropics? In view of the recent discussions on linking up, I cannot see why we should require in this country so high a pressure as 100 kilovolts. With regard to the great height of poles abroad, was this brought about by the cart drivers using very long whips or was it to avoid tree-cutting and ground-levelling? I firmly believe that to keep to the triangular spacing is of great importance in this country, and discussions of recent years go to prove that telephonic interference does take place when the wires are spaced otherwise. Of course in countries which are only just being developed, the triangular spacing is not so necessary and telephones belonging to the power supply authorities can, and should, go along a separate track, and then when failures of the line wires take place the telephones necessary for quick replacement of wires, etc., are not involved, as would be the case with the tower shown in Fig. 1. I should like to draw the author's attention to the channel iron cross-arm in Figs. 8 and 11; surely this is the wrong way for a terminal pole. If placed as "*a*" in Fig. E herewith the bolts are longer than necessary, and with the heavy pull to which the cross-arms are subjected the flanges will cut into the wood of the pole. If put as "*b*" in the same figure, then all the pull comes on the bolt heads. With reference to Fig. 9, I read that the economical limit of pin insulators is 72,000 volts not 66,000 volts. With reference to the design of insulators, on page 424 the author says that an insulator should be so balanced that it does not depend upon corona to relieve overstressing, and, on the same page, that well-designed insulators are recognized by the small amount of corona just before breakdown. Does he mean that the less the corona formation before flash-over, the better the insulator? Also can he give some information as to what effect the climate has upon the design of insulators, i.e. whether an insulator designed for 100 kilovolts in America would or would not be used for the same voltage in Africa? I do not agree entirely with his remark on page 424 that high-tension insulators must be designed to withstand the rapid oscillations set up by lightning. If this is necessary with high-pressure insulators why not with low-pressure ones? He partly admits

Mr. Blakemor

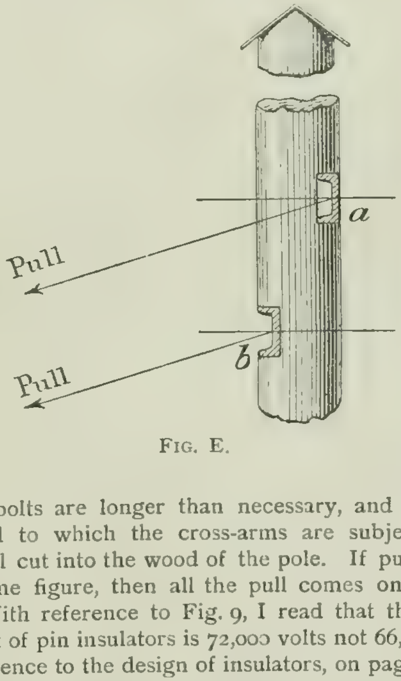

FIG. E.

[illegible] very different results are obtained with different qualities of water, but I should like to know in what district distilled water approximates to rain water. Certainly not in the Potteries. Mr. Digby in the discussion on Mr. Lustgarten's [illegible] n Manchester rain water." Would the author say [illegible] ct the velocity, etc., of the water has upon the [illegible] n voltage, also what thickness of porcelain can, [illegible] e newer methods of manufacture, be thoroughly vitrified. This would be of particular interest to engineers who design their own insulators for various purposes other than overhead work. Will he also give the usual ratio between flash-over and puncture voltages.

Mr. E. S. BYNG (*communicated*): Under Section 3 of the paper, dealing with the "particular design of transmission line material" the author refers to the various types of poles in use, but his remarks are confined to wood, tubular, and lattice steel. As this paper will undoubtedly be referred to as representing the most up-to-date methods of line construction, perhaps some reference should be made to the latest developments in reinforced concrete poles which are now coming to the fore. The points to be considered in comparing the different methods of [illegible] tion are: (*a*) Cost of, and facilities for obtaining, [illegible]; (*b*) cost of manufacture; (*c*) transport; (*d*) cost of erection; (*e*) maintenance; (*f*) life of poles; (*g*) insulation properties. In the case of wood poles the cost of timber is going up by leaps and bounds, and in view of the rapid depletion of the forests, particularly on account of the abnormal demands during the past two and a half years, it is exceedingly doubtful whether stout wooden poles above 45 ft. will be obtainable after the War at anything like a commercial figure. The many [illegible] columns, etc., have been appreciated for some years, but the weight of concrete has hitherto practically prohibited this system from being utilized more generally for overhead transmission routes. In the latest development of ferro-concrete poles there are at least two or three manufacturers in this country who have adopted a hollow [illegible] e round, and others triangular, but in [illegible] ct is the same, namely, to leave out the [illegible] where it is not required for the strength of [illegible] The weight of concrete as compared with a [illegible] even more. Some three or four weeks ago [illegible] The poles in question were [illegible] that a similar pole had been tested to destruction and withstood a horizontal pull at the top of 90 cwt. before collapsing. One of the chief points about these ferro-concrete poles is the density and uniformity of the concrete. This is obtained by a special method of manufacture consisting of an oscillatory-vibratory motion applied to the moulds whilst the poles are being manufactured, but before the "initial set" occurs. The patentees of this system contend that as the concrete is perfectly homogeneous and impervious to moisture the pole after erection is practically indestructible. A further advantage claimed for hollow poles is that the design and construction allow for any number of brackets or arms to be attached after erection. There would appear to be no difficulty in now obtaining poles to any height required for power transmission, as one firm are preparing designs for wireless telegraph masts of nearly 700 ft. height for use after the War. In a paper by Mr. J. Orchiston on "Telegraph Poles in New Zealand,"* it is stated that over 3,000 concrete poles had been recently erected in New Zealand and these had proved a great success, although one objection to their extended use was the question of transport. This is certainly a factor which has operated in the past against the use of ferro-concrete poles for power-transmission work where poles of considerable height are frequently required, but this difficulty has been overcome to some extent by the reinforcement being designed so that it can be put together and the structure made on site. The amount of steel reinforcement is approximately only one-third of the weight of steel used in an equivalent pole of all-steel construction, therefore the weight of material (steel and cement) to be transported to convenient places for manufacture at intervals along the route would be considerably less than that of an all-steel pole (either tubular or lattice work). A suitable aggregate for the concrete can generally be found in the immediate vicinity, and as this represents by far the greater proportion of the material required, the freightage is consequently reduced to a minimum. In these circumstances the initial cost of ferro-concrete poles now compares favourably with that of any other type of construction, although this would not be of first importance if the annual charges were equated when working out the economics of the alternative proposals. In the case of the former the maintenance and depreciation charges would be practically nil, but in either wood, tubular, or lattice work poles these are quite an appreciable item, particularly in the case of the latter where the framework has to be painted at frequent intervals in order to prevent corrosion which would otherwise quickly occur.

Mr. Byng.

Mr. S. DONKIN (*communicated*): The curves given on [illegible] obtained. I have checked an existing extra-high-tension power line, for which my firm were responsible, on Salisbury Plain, in accordance with the methods employed by the author, and I find that although I am able to agree with his statements on page 417, nevertheless, an economi- [illegible] n line with [illegible] doubt due to the schedule of prices of poles, the prices of higher poles increasing at a greater rate than shown by the author. The curve, however, is almost horizontal between a span of 200 ft. and one of 300 ft., showing that it would be equally economical to use either of these spans. As this is a condition which may often arise in working out economical spans, it would appear to be a proper generalization that the shorter span should then be chosen, as it has the effect of making the whole line less likely to break down, that is, it increases the factor of safety. Very little is said in the paper in connection with pin-type insulators, but as this type is very largely used and will probably continue to be adopted for lines of medium pressure, it would appear desirable that some rule should be made as to the factor of safety on the insulator pin itself. It is impracticable to make the pin large enough and strong enough to stand the stress due to the load on one span under Board of Trade conditions if it is assumed that the span on the other side is broken. A strength that has proved satisfactory in practice is to have the pin stressed up to its elastic limit with the Board of Trade load on one span when the neighbouring span is broken, and to make the pin of mild steel so that it will bend and the maximum stress be immediately released. With such an arrangement, however, it has been found desirable to anchor the conductor wires at every five spans on shackle insulators, looping the conductor between the two shackles so that any bad derangement of conductors is always limited to a length of five spans, the poles at every five spans being sufficiently stayed in both directions with stay wires to hold up the line if all the conductors are broken on one side of it.

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* [illegible]

* [illegible]

Mr. J. A. MORTON (*communicated*): With reference to the necessary clearance between conductors to prevent the same swinging together, it is evident that Fig. 3 is based on the Board of Trade wind pressure of 25 lb. per sq. ft. and that the diameters of conductor given are not diameters of solid conductors but refer to stranded conductors. It would have been better if the conductor sizes were stated in sectional areas. For instance, a 0·505 in. diameter conductor is evidently a 0·15 sq. in. copper strand, and the 0·415 in. conductor a 0·1 sq. in. strand. I consider that the spacing between two horizontal conductors should be equal to the swing from the vertical calculated at minimum temperature with the maximum wind, i.e. under the assumed worst conditions, which in England are those laid down by the Board of Trade, viz. 25 lb. per sq. ft. wind pressure at 22° F. In the case of two wires in the vertical plane, the clearance of 1 ft. per 100 ft. of span given by the author is a good rule; I generally make this vertical clearance half the horizontal clearance, which has been found to be a safe figure. I consider, however, that instead of arranging six conductors as in C1 (Fig. 2) the two middle conductors should be spaced slightly further apart than the two top and bottom conductors, which would give a compressed form of B2 in the same figure. This adds a little to the length of the middle cross-arm, but helps to prevent fouling by snow loads. The clearances laid down by the author in Fig. 3 are, I take it, intended for use with pin insulators and not with suspension insulators, which can themselves swing out of the vertical under windage stress. If suspension insulators are used I consider that in addition to the theoretical horizontal clearance calculated for use with pin insulators the spacing should be increased by the length of one suspension string so as to allow for the swing of the suspension insulators. For the same reason the horizontal distance between a conductor and the pole or mast should be such that a minimum clearance is given when a suspension insulator has swung, say, 45° from the vertical. If this swing is not allowed for, then it might come about that the conductor would touch the pole in a heavy wind when carried by this pattern of insulator. With regard to the comparison of assumed wind and ice loadings in which the author compares the factors of safety used in Great Britain, U.S.A., and Canada, I think there is something wrong with the figures given. The Board of Trade wind pressure of 25 lb. per sq. ft. is assumed to be the pressure on a plane surface and is equal to $25 \times 0{\cdot}6 = 15$ lb. on the projected area of the conductor. The U.S.A. and Canadian wind pressures of 8 lb. and 11 lb. per sq. ft. respectively are the windages on the projected area of the wire and should not be compared with the 25 lb. per sq. ft. in the Board of Trade rule, but with 15 lb. per sq. ft. This would make the resultant load in the U.S.A. case 1·35 lb. per ft. instead of 1·05 given by the author, and in the case of Canada 1·32 lb. per ft. instead of 1·035 lb. This means that compared with our factor of safety of 5 in England their factor of safety is nearer $2\frac{1}{2}$ than 3. With regard to the author's remarks regarding the Board of Trade factor of safety for conductors, it might be pointed out that in calculating the erection sags according to the Board of Trade Rules the sag under the worst conditions of 22° F. and 25 lb. wind pressure is calculated and then the corresponding erection sag has to be worked out at, say, a temperature of 60° F. without wind, to get the erection sag under normal conditions. The Board of Trade Regulations state that the elasticity of the wire should be ignored, although I do not understand the logic of this. For instance, taking a 0·1 sq. in. conductor with a 200 ft. span, the sag under the worst conditions comes out at about 2·8 ft., and the corresponding erection sag at, say, 60° F. without wind would be 3 ft. That is to say, if the wire is erected at 60° F. with a 3 ft. sag, then under the Board of Trade worst conditions the sag would be 2·8 ft. as called for by the Regulations. If, however, the elasticity of the wire is ignored, then the corresponding erection sag at 60° would come out at 3·64 ft., and this is larger than is necessary to give the factor of safety of 5 under the worst conditions. That is to say, the Board of Trade worst conditions are never actually realized, and the wire would, at 22° F. and 25 lb. wind pressure, have a factor of safety considerably over 5; in this case it would be nearer to 6, owing to the elasticity being ignored in calculating the erection sag. Referring to Fig. 6 giving the costs of steel and wood supports, it seems to me that the cost of erection should be included to get a proper comparison. In the case of a wood pole the erection usually costs much less per pole than in the case of a steel mast, because the latter requires painting after erection, and may require foundations (depending on the type of base), and these should be taken into account in making comparisons. Strictly speaking, however, it is not correct to base these comparisons merely on the capital cost. The annual charges are different on steel and wood poles even if it is assumed that the length of life is the same in each case, so that instead of the capital costs being compared it would be more correct to compare the annual charges, consisting of interest, depreciation, maintenance and wayleaves. [illegible] The author mentions that "a span of 150 ft. appears never to be justified on economic grounds," this statement being based on the use of A-poles, and I think that in many cases where the lines are sufficiently light for single wood poles to be used 150 ft. will be found an economical span. The author is rather in error in stating that earth-wires are never flexibly supported. It has been the practice of my firm for some years to carry the earth-wire on a small insulator, the earth-wire being bound to this insulator by a flexible binder just as is done in the case of the line wires themselves, in order that the earth-wires shall not suffer from crystallization any more than the line wires. Referring to his remarks on "Loads at Angle Poles," it is true that when calculating the resultant angle load the actual longitudinal stress in each of the two adjacent spans should be taken because the maximum wind pressure cannot come on both the spans; but this is rather a refinement. As a matter of interest I worked out two particular cases and found that in working out the stress for an angle of 105° the theoretical correct resultant stress amounted to about 15 per cent less than the figure obtained in the usual way by assuming that both spans at the angle had the maximum stress in them. For an angle of 150°, however, the figures came out practically the same by both methods. It is not always necessary to provide strain insulators at these angle poles, two ordinary pin insulators in series can often be used to negotiate, small change of direction with light wires, which is often cheaper than using strain insulators. With regard to the question of line insulators being designed to deal with lightning voltages, these usually consist, according to Mr. F. W. Peek, of half-period impulse waves of 100 to 200 kilo-periods periodicity. These lightning or impulse voltages are of [illegible] applied very quickly, i.e. for a very limited time, and the spark-over under such impulses does not occur at the ordinary 50-period spark-over voltage, but at higher values. These impulse spark-over voltages vary with different patterns of insulators, but I think that for practical purposes they might be left out of the question, because an insulator properly designed for a certain line voltage at, say, 50 periods is not likely to break down under these impulse voltages, which are applied for so short a time that there is not time for the insulator to break down under them.

Mr. E. T. [illegible] (Communicated): A paper having this title can hardly be considered complete when it deals [illegible] In America, where long-distance transmission has been developed to its furthest extent, it will be found that practically 50 per cent of the [illegible] to the year 1915 when the scarcity of aluminium began to [illegible] economical span length (which is always dependent upon the contour and other local conditions), that I feel sure only considerations of space can have prevented the author from dealing fully with this aspect of the subject. In the table herewith comparison is made between copper, aluminium, and aluminium-steel strands of the same conductance. The last-mentioned conductor is made by substituting for the core a strand of high-tensile steel having one-seventh the area of the complete cable. The method of calculating the tensile strength and the sag of such a composite conductor was fully treated in an article by Mr. E. T. Driver and the writer some time ago.*

	Copper	Aluminium	Aluminium-steel
Area, equivalent sq. in.	0·100	0·100	0·100
" actual	0·100	0·107	0·108
No. of strands	7	7	7
Core	copper	aluminium	steel
Weight per ft. lb. ...	0·400	0·200	0·300
Diameter of conductor	0·408	0·520	0·570
Tensile strength, lb. per sq. in.	60,000	28,000	47,000
Maximum sag at [illegible] F. on 500-ft. span, ft.	10	25	12
Height of double-circuit tower, ft.	60	75	62
Cost of towers (11) per mile	£770	£440	£700

This comparison takes no account of the fact that in the normal conditions of the market bare conductors in aluminium or aluminium-steel are from 10 to 40 per cent cheaper than the equivalent copper, but it merely shows how wide is the variation in the cost of towers for different conductors. The towers differ from those shown by the author in having three cross-arms as is usual in American practice, but this does not affect the comparison. No mandatory rules are in force in the United States covering the erection of transmission lines; it is felt that the engineers concerned are those best calculated to know what is best and safest both in their own interests and in those of the community. The recommendations of the Joint Committee referred to on page 416 were formulated to govern railway crossings, and construction across open country will generally be a little less conservative. Conditions in such States as Maine and Arizona are so diverse that no universal standard of loading can possibly be adopted.

Mr. G. V. Twiss (in reply): The President gave an indication of one *raison d'être* of the paper when he mentioned that it had been brought forward by the Council together with the paper by Mr. Vernier on "Wayleaves" in view of the present importance of electric supply developments in this country. Hence a good deal of the discussion has had reference to factors of safety and the Board of Trade Regulations. I have reason to hope that this matter will not be left exactly where it is and that some good will come of the paper in that direction. Certainly recent developments in all branches of activity have shown that many things which, under ordinary circumstances, would

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* [illegible]

Ir. Twiss. be immovable, are amenable to modification under war conditions. If advantage is therefore taken of the present opportunity to obtain greater facilities in regard to wayleaves, and modifications of restrictions, the transmission of electrical power will be greatly facilitated, with consequent benefit to the electrical profession and industry and thence to the country.

In regard to Mr. Trotter's reference to the pressure of 30,000 volts for the limited lines in this country, I quite agree that for such lines the use of higher voltages is not justified. There is an economical pressure for every condition, which would take into consideration the extra cost of transformers, etc., and transmission lines in this country are designed for pressures closely in accordance with their respective economical voltages. If greater developments ensue on the lines indicated in the "Introduction" to the paper, then doubtless the economical pressures would be considerably higher than those at present used. In regard to the critical point mentioned by Mr. Trotter at which it is cheaper to send coal by train than to transmit electrical power, this presumably only occurs with very small amounts of power to be transmitted over long distances, and when large amounts of power have to be transmitted over any reasonable distance it is surely always cheaper to transmit electrically. Mr. Trotter states that I am wrong in making comparisons with countries which have perhaps no coal at all or countries where a network of railways does not exist. I quite agree that if a network of railways is largely used for transmitting coal for the purpose of subsequently generating electrical power in more or less small quantities, then the comparison does favour the country with the coal. There is, however, no very great difference between the cost of generating in large bulk from coal and that where water power is used. The latter must of necessity be used on site, and if it is to be transmitted to consumers at any distance this must be done electrically or not at all. Coal, on the other hand, can be transmitted in trucks and used piecemeal, but that is no argument for doing so, and it seems to me that had coal the same disability as water power of not being transportable in trucks, we should at the present time be generating the bulk of our electrical energy at the coalfields and transmitting it at high pressures with far greater all-round efficiency than we at present approach.

I regret I am unable to agree to Mr. Trotter's suggestion that the ratio of 5 : 2 between the factors of safety in this country and those abroad represents the ratio of the quality of the work. It must be remembered that much of the early American work was of the nature of pioneering and was presumably erected without much regard to any particular factors of safety. The security of their recent lines and also of those of the Canadian Hydro-Electric Commission, who use similar factors of safety, would appear to compare favourably with that obtained in this country. With regard to the question of the Board of Trade factors of safety, I endeavoured to show in the paper that a consistent margin of security has not been given owing to the fact that we occasionally get loadings more severe than the Board of Trade assumed loadings, in which case the margin of security with a small conductor is less than with a large; hence it is not a question of reduction of security but merely one of consistency—that is to say, of having equal security on all sizes of conductors. Mr. Wigham in his remarks draws attention Mr. Twiss. to this point, and Sir William Slingo's remarks substantiate it.

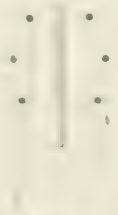
I do not suggest that the Board of Trade have limited the length of spans. Indirectly, however, as is shown in the paper, the economical span length is longer and the transmission-line construction more economical the tighter the conductors are strung, so that the low tension of stringing necessitated by the Board of Trade Regulations does indirectly limit the length of spans by making longer spans uneconomical. In regard to the short spans used by the Ontario Hydro-Electric Commission for low-pressure wires, these are distribution lines which are light enough to allow single poles to be used. Transmission lines are usually too heavy for the economical use of such poles, and the curves in the paper were therefore taken on **A** poles.

Mr. Dickinson's reference to the limitation of pressure by the Board of Trade gave Mr. Trotter the opportunity of making it quite clear that the Board of Trade have no objection to the highest voltages. Mr. Dickinson suggests that the next revision of the Board of Trade Regulations should be framed in conjunction with the Institution. Mr. Jacob also made a similar suggestion. Mr. Trotter's reference to the Electrical Adviser not being allowed to have an advisory committee and his remark that the responsibility for the factors of safety rests on the shoulders of one man would also seem to indicate that he is not averse to that course. The matter is an important one from the national point of view, and also from the point of view expressed by Mr. Dickinson, that our Overseas Dominions often take our Board of Trade Regulations as a precedent not to be departed from, with the result of unduly increasing the cost of schemes—if not, in fact, making some uncommercial. In any case it would seem desirable that Board of Trade Regulations should be marked with a footnote to make it clear that they only apply for the particular conditions obtaining in this country, and that the different conditions abroad might justify considerable deviations therefrom.

The over-testing of insulators is of course more likely to occur mechanically than electrically, as electrically the flash-over of an insulator is to a large extent its own safety valve. As Mr. Dickinson states, it is important to limit the mechanical test to a small percentage above the working load, and those insulators which are tested considerably beyond that for the purpose of proving the accuracy of design should be destroyed to ensure that they will not be used on the line. Mr. Dickinson states that it is necessary to vary the degree of insulation according to the requirements of different parts of the line. This is to my mind very true and I am glad to see this authoritative statement. I quite appreciate the difficulty when insulators become covered with salt incrustation. On one system where this trouble is serious a section of the line had to be provided in duplicate, each part of this section being alternately taken out of commission for the purpose of cleaning the insulators. I agree with Mr. Dickinson that it is always better to avoid erecting a telephone circuit on the same poles as the transmission line; but where this is unavoidable, care should be taken to erect the telephone lines on insulators sufficiently large to prevent leakage, having regard to the high potential which may be induced in [illegible] s are often used, and unless the users [illegible] span length upon telegraph practice, I am unable to see what otherwise influenced them. The conditions for telegraph lines, particularly where there [illegible] h of 180 ft. for such telegraph lines is too long [illegible] Sir William states has already been [illegible] economy. The experience which he relates as to the damage on telephone and telegraph lines during the great storm in March 1916 is very interesting and bears out, as do his deductions therefrom, the point I have endeavoured to make in the paper, namely, that under snow and ice conditions the small wires are more highly stressed (or have a smaller factor of safety) than larger wires.

Mr. Jacob's remarks show he is sanguine that we shall eventually have larger power developments and trans- [illegible] we should then be obliged to reconsider some of our existing regulations, or alternatively have to incur greatly increased expenditure. The use of aluminium calls to mind the [illegible] The effect of elasticity is appreciable, [illegible] e strung at higher tensions justifying longer [illegible] effect of elasticity is considerable, and as between copper and aluminium is the more considerable on aluminium conductors. The data given by Mr. Jacob in regard to aluminium wires with steel cores is inter- [illegible] tor as a catenary from which a trolley wire is [illegible] l.

[illegible] regard to working for security, but I think that security [illegible] istent. I note that Mr. Highfield likes the C1 arrangement of the conductors (see Fig. 2). The one [illegible]



[illegible]

Mr. Twi very novel method of painting the inside of tubular poles. I agree with him that the use of longer spans is a great advantage, for the reasons which he gives, and that there is no difficulty in using 400-ft. spans in this country with steel poles. Tighter stringing of the conductors has, however, the same effect at less expense, and as the curves show, with tighter strung conductors spans of 400 ft. can often be economically negotiated by wooden poles. I am glad that Mr. Highfield agrees as to the danger of over-testing insulators.

In reply to Mr. Richards, the curve in Fig. 3 does not embody temperature, as before using the curve one would already have worked out the sag at the required temperature, and from this figure the curve then indicates the necessary clearance. The figures for sag and clearance in Fig. 3 may be read in any unit, inches or feet, and the conductor curves are calculated upon the Board of Trade loadings. In regard to the temperature at which the maximum sags are to be calculated, I agree with Mr. Richards that a definite ruling is wanted on this point. I have taken a temperature of 132° F., which is a range of 110 degrees upon the Board of Trade Regulations, and a temperature of 132 F. in the sun is sometimes reached in this country. My statement that the larger the conductor the longer the economical span length, is applicable to either wood or steel, whichever gives the cheaper line.

I am pleased to note that the curves of economical span lengths are confirmed by Mr. Wigham's practical results.

Mr. Wigham asks what is the advantage of the enormous tower shown in Fig. 1. These towers are of the minimum height to give a clearance of 22 ft. on 500-ft. spans. The economy of a span of 500 ft. for this case is substantiated by a curve worked out exactly on the same lines as Fig. 6. That the economical span for such a curve is longer than any shown on the curves in Fig. 6 is due to the fact that for the double-circuit curves in Fig. 6 the cost of insulators and accessories is only taken at £4 per pole, which is sufficient to include insulators, etc., for a pressure of 30,000 volts. The transmission line shown in Fig. 1 is for 100,000 volts and a larger sum is required to cover the cost of the insulators, which therefore gives a different curve and the dip in this curve occurs opposite a greater span length. In view of Mr. Wigham's question I should like to make it clear that the curves C_1, C_2, C_3, and C_4, in Fig. 6, are merely given to show the completion of the process of finding the economical span, and at the same time to give some examples, but such examples are by no means comprehensive and one would plot a fresh curve in the manner shown for each individual case—a few minutes' job by this method.

Mr. Mordey has raised a point which came up in a previous paper in regard to the difference between copper and aluminium conductors as regards the deposit of snow or ice upon them. Mr. Jacob's remarks apply to this point. The test mentioned by Mr. Mordey is certainly novel and interesting. There would, however, be a certain amount of leakage current over the surface of the insulators, so that any discoloration of the liquid would not be entirely due to the effects of current passing through the porcelain. A delicate galvanometer can be used for the same purpose, and the leakage current over the surface can be shunted so that the galvanometer only indicates the amount of current passing through the porcelain.

. Twiss. It is interesting to note from Mr. Sparks' remarks that overhead wires were working at a pressure of 2,500 volts and were being put up for 10,000 volts at the inception of the electrical industry in this country. The 30,000-volt scheme which Mr. Sparks described uses, of course, the highest transmission line voltage yet employed in this country, and I am glad to note that the average span length is 360 ft. Mr. Sparks' remarks show that he has already adopted a flexible clamp for earth wires, which practice I advocate.

In reply to Mr. Astley's first point, the argument given in the paper on this subject is, as stated, for structures supported by vertical reactions, which is the usual practice with lattice steel masts. Mr. Astley's remarks obviously apply to a structure supported by horizontal reactions, so that the objections he makes to my conclusions do not apply. In regard to the use of hemp, which Mr. Astley appears to advocate, hemp can of course be used, but in my opinion it is not necessary or justified with English porcelain, though it may or may not be necessary with certain classes of brittle porcelain. I am interested in the designs which he shows of insulators arranged with a patent method of using hemp. If hemp must be used then I agree that this is as good a way of applying it as could be designed. At the same time, however, one cannot fail to notice that this design introduces sharp edges, thereby causing concentrations of flux and also air spaces between the dielectric and the electrodes, which air spaces are likely to be in a state of static breakdown and to set up local heating and chemical action. These effects are detrimental to the insulator. The **V** threads on the porcelain also weaken it and concentrate the mechanical stress therein, so that I should always expect the porcelain in such an insulator to fail at a lower load than an insulator of similar proportions where such grooves are not used. The effects of expansion and contraction can be and are successfully combated in the latest types of metal-hooded insulators by the employment of a number of devices which do not introduce other evils. The tests I mention may be performed after the cement has thoroughly set and hardened, that is to say, after the early months to which Mr. Astley refers, which I think disposes of the ground upon which he questions the correctness of such tests for the purpose. I quite agree with his remarks as to the failure of insulators being largely due to cracks and porosity; in fact, I make this point quite clear in the section of testing of insulators under "deterioration tests." It is the recognition of this trouble which has led to the perfection of various devices of design in connection with the cemented insulators referred to above, and the adoption of these methods has successfully combated expansion and contraction troubles.

In regard to Mr. Blakemore's interpretation of the "Introduction" to the paper, I hope and believe English engineers need no urging in the direction indicated. The introduction was not intended to bear that interpretation, so that the meteorological and other statistics required hardly arise therefrom, and in any case the time and space for this reply do not permit of their being gone into. With regard to the height of poles abroad, clearances greater than usual are occasionally required on account of long whips, but as a rule the greater height is justified on the ground of the length of span alone. I quite agree with Mr. Blakemore's remarks in regard to the position of the telephone wires in respect to the transmission line and the use of a separate line for telephones wherever possible. The channel section has been introduced in Figs. 8 and 11 with the object of showing how the connecting pieces are attached to the cross-arm. At angle positions there is an insulator on both sides of the channel, so that the channel is obliged to be in the position shown in respect to one of the insulators. At terminal positions, however, I agree with Mr. Blakemore that the channel should be fixed in the reverse position. With regard to the economical limit of pin insulators, the relationship varies slightly with the price of metal, as when the price of metal is high it is to the advantage of the pin insulator, which uses less. The curve is based upon recent high prices; hence the point of economy is slightly above 66 kilovolts, but ordinarily 66 kilovolts is, as stated, the limit. In reply to Mr. Blakemore's question as to whether I mean that the less the corona formation before flash-over the better the insulator, the answer is in the affirmative. In regard to the effect of climate upon the design of insulator, I would refer him to Mr. Dickinson's remarks and my reply thereto. Mr. Blakemore says that if it is necessary to design high-pressure insulators for high frequency why not low-pressure ones? At the bottom of the second column on page 424 of the paper I state that it is desirable to do so. That it may not be quite so necessary, however, is due to the fact that according to the observations of those interested in the point, transmission lines for pressures below 30 kilovolts are less affected by lightning troubles than at the higher voltages (above a certain voltage, however, the liability to trouble is again less). This may be due to the fact that lines up to 30 kilovolts, as their pressure indicates, are shorter and therefore less likely to be in exposed positions. Then again, as I state, the electrical factor of safety on the insulators for such lines is as a rule much higher than on the larger insulators for higher voltage lines, so that the insulators will be better able to withstand surges and oscillations. Joulean losses are heat or I^2R losses. In regard to Mr. Blakemore's query as to what effect the velocity, etc., of the water has upon the breakdown voltage, I presume he is referring to the flash-over voltage under spray. In the standard spray test, water is precipitated on the insulator at an angle of 45° and at the rate of 1 in. in 5 minutes, and the pressure at the nozzles is generally taken to be about 40 lb. per sq. in. If the velocity of the spray is increased considerably then the splashing effect of the water is magnified, forming a tendency to wet the underside of the sheds excessively, thereby reducing the flash-over value. Increasing the amount of water without increasing the velocity also brings about a reduction, but in either case the reduction is not considerable. I have no information as to the districts in which distilled water approximates to rain water. A thickness of 1 in. of porcelain can, as a rule, be thoroughly vitrified. The ratio between flash-over and puncture voltages must vary considerably with different types of insulators, having regard to the nature of the electrodes and the relative disposition of porcelain and air. There can be no usual ratio. Mr. Twiss.

Mr. Byng gives some useful information in regard to reinforced concrete poles, a subject which I have not dealt with in the paper. In my opinion concrete poles

Mr. Twiss are very sound, especially as they are not subject to corrosion like steel poles or to rotting like wood poles, and they should therefore show to advantage from the point of view of maintenance and durability. The main problem seems in my opinion to be that of weight. In this respect hollow poles obviously show advantages over solid poles, which is borne out by the figure given by Mr. Byng. He does not, however, compare the weight of a concrete pole with that of an equivalent wood or steel pole. Such figures as I have seen indicate that a concrete pole is between two and three times heavier than the equivalent wood or steel pole. If a pole is made on site its weight is not so important an item. As in most things, however, to ensure the use of consistently high-grade materials, the best workmanship and supervision, necessitates the manufacture being carried out by properly trained and organized men in a properly equipped place. Under these circumstances, transport of the poles to site becomes necessary and their weight is of importance. In view, however, of the increasing scarcity and consequent cost of timber for poles and other disabilities in regard to steel, the possibilities of ferro-concrete poles are considerable.

As Mr. Donkin states, the economical span length must vary slightly from time to time in accordance with fluctuations in the price of material for poles. Mr. Donkin suggests that of two spans of equal economy the shorter should be chosen having regard to the mechanical point of view, but I always consider a transmission line as conductors insulated as far as possible by air, and the points of support as necessary evils, so that from the electrical point of view one would be inclined to choose the longer of two equally economical spans, which also often facilitates wayleaves. Mr. Donkin asks whether it is impracticable to make the pin of a pin insulator strong enough to stand the unbalanced load of a conductor. I see nothing to prevent it, but as the schedule on page 432 shows, no ordinary means of attachment is strong enough to hold it, and I do not see what advantage would be obtained if some special arrangement were devised for the purpose.

I agree with Mr. Morton that the curve in Fig. 3 would be better with the actual size of stranded conductor mentioned instead of merely the section, and I am adding this. In the case of pin insulators the figure of sag only will indicate clearance, but in the case of suspension insulators the length of the suspension insulator must be added to the sag to indicate clearance. Mr. Morton considers that the clearance between two horizontal conductors should be based upon the swing from the vertical. I presume that by "swing from the vertical" is meant the horizontal distance between the vertical plane of rest and the vertical plane into which the wire can swing; if so, that is exactly what the clearances given by the curves in the paper are based upon, and the only question is as to the length of sag from which such swing is calculated. Mr. Morton takes the length of sag as that at the minimum temperature and maximum wind. The maximum wind, however, may occur at a higher temperature, and consequently when there is a greater sag than occurs at the minimum temperature. On the other hand, the maximum wind is hardly likely to occur at the maximum temperature; hence the clearance should be based on a sag somewhere between these extremes. In the absence of any definite rule, however, Mr. Morton's is near enough for all practical purposes, and my curves may be used therewith, that is to say: Calculate the sag which occurs at minimum temperature and maximum wind, and with this figure the curve will indicate the required clearance. I am indebted to Mr. Morton for pointing out that the U.S.A. and Canadian figures of wind loadings are the windages on the projected area of the wire and not, as in the case of the Board of Trade, on a plane surface. One or other must therefore be equated to make it comparable with the other. I agree that this increases the resultant load on the U.S.A. and Canadian conductors, but I am unable to agree that it reduces their factor of safety as compared on the same basis with ours. As the stress of 30,000 lb. per sq. in. is obtained with the loading of 1·35 lb. per ft., then when any lower loading occurs, as for instance 1·05 per ft. or 0·658 lb. per ft. the stress is reduced and consequently the factor of safety is increased. I am glad Mr. Morton considers the suggested rule for clearance between wires in the vertical plane to be a good one. I am also inclined to agree with him as to the arrangement of conductors, and I have dealt with this point in my reply to Mr. Highfield. I am pleased to note Mr. Morton's remarks with reference to elasticity, which I have referred to in my reply to Mr. Jacob. I certainly think that elasticity ought not to be ignored.

Mr. Twiss Mr. Morton's remarks are quite true in regard to the cost of erection of steel masts as opposed to wooden poles, and I am glad to see that, notwithstanding these, he still considers my suggested method of finding the economical span to be very useful. I do not claim it to be perfect, as it would be impossible to take everything into consideration however long and tedious the process were made, but it certainly gives a definite idea of the relative economies of definite spans, and I believe it to be the first practical method by which this could be obtained. I agree that where lines are sufficiently light, single wood A poles can be used with economy at shorter spans than 150 ft. I have mentioned this point in my reply to Mr. Trotter, with the addition that it is very rare that transmission lines are so light as to permit of this.

In regard to the statement in the paper that earth wires are never flexibly supported, Mr. Sparks has shown that this was done in the case of his latest 30,000-volt line for the Powell Duffryn Company, and now Mr. Morton states that it is the practice of his firm. I am glad of this, notwithstanding that it shows my statement to be partly incorrect, as at the same time it supports the correctness of my argument. I note that the method used by Mr. Morton's firm is that of attaching the earth wire to an insulator by means of a flexible binder. The insulation of the insulator is of course not used in this case, and I think that the flexible earth-wire clamp shown in Fig. 23 would be at least equally flexible and rather better. Mr. Morton has worked out some cases on the point I make in reference to loads on angle poles, and I agree with him that the difference is not material unless a large angle is to be negotiated; even then, as he says, it is something of a refinement. With regard to his reference to half-period impulse waves as referred to by Mr. Peek, this is not the most severe effect on insulators, as all insulating materials will stand a higher potential applied for such limited

r. Twiss. periods. A more severe effect is the application of high-frequency oscillations.

Mr. Pannell gives some useful information and comparisons in regard to compound aluminium-steel conductors. The use of this type of conductor occasions surprisingly small sags and therefore has an important bearing upon the economy of capital cost of transmission lines. Mr. Pannell, who is resident in Canada, refers to the Joint Report Recommendations being conservative. This is certainly significant having regard to the relationship of the recommendations of such Joint Report Committee to those of the Board of Trade. Mr. Twi

BIRMINGHAM LOCAL SECTION, 25 APRIL, 1917.

r. Kapp. Dr. G. **Kapp**: The summary which the author has given is in my opinion too short; he has credited the members with too much intimate knowledge of a subject which is highly specialized and new to many of them. It is very satisfactory to find from the paper that English engineers have been so successful with extra-high-tension transmission lines, a subject which has up to the present been generally considered to be the special province of American engineers. I think the author's allusion to the so-called "cheap water power" requires qualification, because if this popular belief were allowed to crystallize into a conviction it would cut the ground from under such enterprises as are the subject of the paper. So far as the cost of energy is influenced by capital outlay, water power is by no means cheap. The average capital cost of Italian hydro-electric works is about £30 per kilowatt; whereas in a paper recently presented to the Institution of Civil Engineers the cost of the electricity supply works at Walsall, in which steam plant is installed, was given as a little under £8 per kilowatt. Whether the cost of energy is less in a hydro-electric works than with steam plant depends on two things: the load factor and the utilization of the by-products from the coal. In discussing the potential gradient in a string of insulators the author alludes to the effect of series and shunt capacity. It is interesting to note that the influence of shunt capacity has also been found to constitute a difficulty in the so-called Wurtz lightning arrester. It is well known that these appliances cannot be used for very high voltages because the potential gradient between the first few cylinders close to the line is extremely steep, and the addition of more cylinders at the earth end of the series does not materially flatten it. This is due to the shunt capacity. An Italian engineer, Mr. Moligniano, has overcome this difficulty by artificially increasing the series capacity between the cylinders so as to swamp almost completely the shunt capacity. By this means he obtains an almost straight-line potential gradient, with the result that the Wurtz arrester can be used on lines of very high voltage. The author advocates the arrangement of wires shown in B3, Fig. 2, for duplicated three-phase lines, because no wires are in a vertical line. I presume that the advantage of so placing the wires is that in the event of an upper wire breaking it will fall clear of all the others, but I doubt whether one can rely on an absolutely vertical path of a broken wire. A wire generally breaks under wind pressure, and it seems to me that the broken end will then be blown sidewise and will foul other wires whatever may be the geometrical disposition. An arrangement which is electrically preferable may therefore be adopted, such as the hexagonal disposition so frequently used in Switzerland. It has the advantage of shorter cross-arms and less inductance. With the very high voltage for which the author's lines are designed the reduction of inductance is not of much importance, but with moderate voltages this reduction combined with the increase of capacity has a beneficial effect on the power factor of the line. Dr. Kapp

Dr. C. C. **Garrard**: The paper deals with a subject which will be of very greatly increased importance in this country in the near future. Some people have been under the impression that transmission lines at very high voltages are only necessary or desirable in connection with water power. With a rational use of coal, however, I consider it possible that we could produce electricity at a total works cost (excluding distribution costs) of £2 per kilowatt-year with a load factor of 60 per cent. This approaches the best results attained by water power. Under these conditions extensive overhead transmission lines at high voltages would be very numerous. It is therefore very desirable that the standardization of British overhead equipment should be taken in hand by the Institution and the Engineering Standards Committee, in order that while maintaining the British reputation for high quality in this branch of engineering, as in others, the development of the industry shall not be hindered by the survival of obsolete official regulations. With regard to the testing of line insulators, I should like to direct attention to the method recently worked out in the United States* by which the actual resistance of high-tension insulators is measured. It is stated that by this means insulators having a slight degree of porosity, and which would break down after several years' service, are eliminated before being put into use. I should like to mention a point touched on by the author, namely, the law of corona. Apparently the electric strength of air Dr. Garra

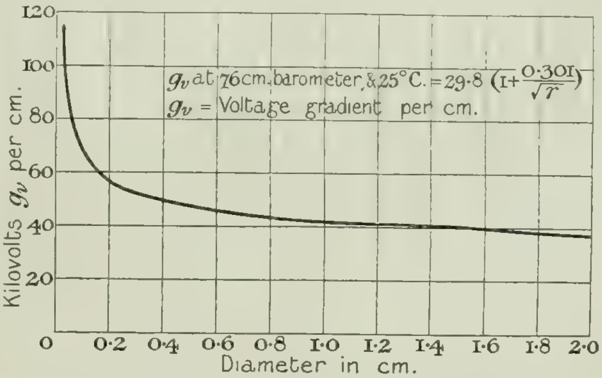


FIG. G.—Visual critical voltage gradient with two parallel wires.

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* *Proceedings of the American Institute of Electrical Engineers*, 1917, vol. 36, p. 77.

Dr. Garrard. increases in the neighbourhood of thin wires, points, etc. [illegible] work has been done in America. Fig. G illustrates the phenomenon in question, and the formula (given in the figure), which was first stated by [illegible] gives the law of the curve. The value of g_v is the greatest possible electric stress in air (i.e. above which the electric corona occurs) in the neighbourhood of a wire or cylinder. A very ingenious explanation has been put forward of these facts, but to my mind a real physical explanation has not yet been forthcoming. I should like to ask in connection with the question of "string efficiency" of suspension-type insulators whether it is possible to get over the trouble of the concentration of potential on the insulators nearest to the line by the adoption of some sort of ground shield as has been done with roller-type lightning arresters. As regards the question of cement for fixing insulators on to pins, I believe litharge and glycerine cement has been largely used for this purpose. Lately glycerine has been difficult to obtain. I should be glad to know if the author can recommend any other cement to take the place of the litharge-glycerine. A cement which sets reasonably quickly is essential for many purposes. This would prevent the use of Portland cement in such instances.

[illegible]gholm. Mr. A. G. [illegible]: I think it is very important that the cost of maintenance of overhead-line transmission poles should be kept as low as possible. No doubt this cost will vary greatly with the climatic conditions, but I should be pleased to learn if the author has any figures showing the cost of maintenance of the types of poles illustrated in his paper. I have frequently found that sheradizing any of the iron fittings and such-like parts is better than galvanizing, as very often the metal is eaten away underneath the galvanizing, leaving only the outer skin of the galvanizing, so that it is difficult by casual observation to detect such action. As it is well known that steel does not corrode when embedded in concrete, I shall be pleased to learn if the author can express an opinion about the use of concrete poles. I think one of the main features in connection with overhead-line transmission should be that the cost of maintenance is kept as low as possible.

[illegible] Mr. F. H. [illegible]: Can the author state the amount of mechanical wear which takes place with suspension insulators?

Mr. Plummer. Mr. F. Plummer (communicated): With regard to the question of ice coatings on conductors, as shown in the table on page 416, it may be pointed out that ice coatings [illegible] were observed on telegraph and telephone wires after the severe blizzard and [illegible]n which caused such havoc on overhead lines in the Midlands on the [illegible] March, 1916. It is estimated that the wind pressure during the storm was well in excess of [illegible] lb. per sq. ft. The Post Office standard for aerial lines provides for a factor of safety of 4 for copper wires at 22° F. under normal conditions, with an average span length of [illegible] yards. The factor of safety is increased to 6 for [illegible] [illegible] The factor of safety [illegible] [illegible] [illegible] the A type of pole construction for heavy stresses, as against either single poles or H poles. The objection to the A pole is the difficulty in securing equal spacing in the vertical and horizontal distances to provide regular squares for the revolving telephone loops on arms of uniform length. On A poles the lower arms are now somewhat longer.

Mr. Twiss. Mr. G. V. Twiss (*in reply*): In regard to Dr. Kapp's remarks, I hope that the paper and the discussion thereon will do something to dispose of any idea which may exist that engineers and engineering firms abroad are the only people who understand extra-high-tension transmission lines. I am glad that Dr. Kapp has referred to the question of the relative cost of electric power from coal and from water. It was not my intention to infer that power from water is necessarily cheaper than power from coal. I would refer Dr. Kapp to my reply to Mr. Trotter (page 442), and I believe my statement to be correct that in large bulk there is little difference between the cost of generating from coal and that from water. Dr. Kapp's remarks in regard to Mr. Moligniano's method of overcoming the effect of shunt capacity with the Wurtz lightning arrester are of interest. The advantage of the B3 arrangement (Fig. 2) does not lie so much in preventing a falling broken wire from fouling a wire below but rather in the prevention of wires fouling one another when unevenly borne down by snow or ice, or springing up when such snow or ice falls off.

Dr. Garrard also refers to the relative cost of generating electrical energy from coal and from water. I quite agree that a more economical use of coal would lead to extensive overhead transmission and necessitate the application in this country of some of the practice which, up to now, has been developed for transmission lines abroad, in connection with the very high pressures referred to in the paper. In that connection, Dr. Garrard's reference to the desirability of an Engineering Standards Committee to deal with transmission lines is a suggestion which may be worthy of consideration. I am acquainted with the method to which Dr. Garrard refers for detecting slight degrees of porosity in porcelain insulators. This method is sound, provided that efficient means are adopted to collect the leakage current over the surface of the insulator, thus only measuring the leakage current through the insulator itself. Dr. Garrard remarks that apparently the electric strength of air increases in the neighbourhood of thin wires, points, etc., and he states that a very ingenious explanation of this fact has been put forward, but he does not mention whose explanation he is alluding to. He also refers to Mr. F. W. Peek, Jnr., but according to such theory as I have seen, including that of Mr. Peek, this variation is only apparent, and in actuality the dielectric strength of air or the critical disruptive gradient (g_o) remains constant for a given density. The critical disruptive gradient has no visible effect, and the visible effect, i.e. corona, requires a higher gradient at the wire surface, known as the critical visual gradient (g_v), in order to supply the necessary amount of energy to cause the breakdown or rupture of the air between a finite radial distance in space away from the conductor, where the stress is g_o, and the surface of the conductor itself where the stress is g_v. The finite radial distance in space away from the surface of the conductor is found to be a function of the size of the conductor, and is expressed thus [illegible] cm., where r = radius of the

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[illegible]

r. Twiss. wire. Hence with small conductors the stress g_v must be greater than with large. The electron theory may also be applied in agreement with the above. I do not know whether or not this may be the ingenious explanation to which Dr. Garrard refers and which he does not accept as the real physical explanation. The use of a shield would draw some of the flux away from the pin of the insulator unit nearest to the line, thereby improving the flux distribution therein. The insulator unit, however, would still have to carry practically the same amount of flux, and consequently the potential gradient in such unit would not be materially reduced. The use of such a shield if well dished would simulate the effect of a large sphere and would therefore have the advantage of reducing the time lag under steep wave-front conditions, but it is questionable whether it would justify the additional trouble and expense from this point of view alone. I think that Portland cement of the quick-setting variety would fulfil Dr. Garrard's requirements.

Mr. Engholm refers to an important point when he mentions the cost of maintenance of overhead transmission poles. According to all American records their steel poles last longer and require less maintenance than their wood poles. This, however, is largely due to the fact that they do not creosote their wood poles as we do. Experience in this country appears to prove that creosoted wood poles are less expensive to maintain than are steel poles. Of methods of covering steel poles sherardizing would be very desirable, but in this country the cost is prohibitive and I have never heard of the method being used for this purpose. Galvanizing, which is so often used in America, I am not in favour of, as if the coating gets damaged (which is so likely to happen in transit) then rust starts at this point, and, as Mr. Engholm states, once started metal is often eaten away underneath the galvanizing. It is consequently almost impossible adequately to check such trouble once started. The important thing is to get the steel on site without any rusting point having started. Paint is liable to get chipped off in transit and rusting to start, and one of the best methods I know of is to immerse the steel whilst hot in linseed oil, which leaves nothing to flake off. It will then arrive on the site ready for erection, free from any starting points of rust, and ready to take a coat of paint. The fact that reinforced concrete poles are not liable to deterioration by rust is a great point in their favour, and I would refer Mr. Engholm to Mr. Byng's remarks (page 440) on the subject of reinforced concrete poles and my reply thereto.

Mr. Twis In reply to Mr. Clough, most of the mechanical wear with suspension insulators takes place at the point of attachment, i.e. between the eye piece of the suspension insulator and the link which connects between the eye piece and the pole. These are usually designed with additional material over and above that required for the mechanical load to provide for wear. Evidently this adequately gets over any possibility of trouble due to wear, as I have never heard of any suspension insulators coming down owing to their link attachment being worn through.

The figures which Mr. Plummer gives as to the amount of ice on Post Office wires during the storm of March 1916 are of great interest. Personally, I believe the A pole to be the best type of wood-pole construction and I am glad to see that the experience of the Post Office is leading them to that conclusion, notwithstanding the objection which occurs with telegraph and telephone lines in regard to the different lengths of the many cross-arms.

ELECTRIC WAVE PHENOMENA IN THE DYNAMO-ELECTRIC MACHINE.

By F. Creedy, Associate Member.

([illegible] 1917.)

Part 1.

GENERAL MATHEMATICAL THEORY.

SECTION 1.

The present paper has been written as an introduction to the exact study of a class of phenomena of constant occurrence in important industrial machinery. The existence of these phenomena is almost unknown to the practical engineer and is barely hinted at in treatises on mathematical physics. While the existence of such a general type of wave is known to engineers, the manner in which it occurs in dynamo-electric machines has never been discussed.

These phenomena are due to a type of electric wave which may be proved to exist in magnetic structures interlinked with electric circuits. It is shown below, indeed, that two types of one-dimensional electric wave exist, viz. that present in cables, which has been so extensively studied by Kelvin, Heaviside, Pupin and many others, and a second reciprocal type in which the functions of magnetic and electrostatic lines are interchanged. This [illegible] hitherto been insufficiently studied and forms the [illegible] of the investigations of the present paper. Such an investigation forms the most suitable basis for a general theory of the dynamo-electric machine.

In Section 2 of the paper we first of all develop a number of fundamental differential equations which are shown necessarily to characterize every dynamo-electric machine. These equations are shown to be a particular case of Maxwell's equations of the electromagnetic field.

In Section 3 these general equations are discussed, and it is shown that their solution is necessarily periodic in time and space and consists in fact of an infinite series of independent harmonic waves (including a constant term—the homopolar solution). Further developments of this section have been published by the author in his paper "The Classification of Electromagnetic Machinery."*

After a short discussion of the methods of connecting the face-conductors we pass to Section 4, in which we [illegible] wave for circuits containing resistance, inductance, and capacity. [illegible] of complex quadratic equation, and a graphical solution [illegible] n 4, many of them being discussed in considerable [illegible]

Before proceeding to the main portion of our investigation we must first formulate a preliminary definition of the dynamo-electric machine from which to start.

The "dynamo-electric machine" consists essentially of two members capable of mutual rotation, a single magnetic flux common to the two, and two electric circuits one on each member, interlinking the flux. In one or two exceptional cases only one electric circuit is used, but these we shall not consider.

Two forms of mechanical construction are in use, one in which revolving and stationary parts are separated by a short air-gap uniform throughout the periphery, and another in which salient poles are used. This latter type, however, is not of general application, being suitable only for continuous current and some forms of single-phase machine, both of which types may from the technical point of view be equally well built with uniform air-gap. We shall therefore consider the uniform air-gap type to be the standard. In order to minimize magnetic leakage the conductors in both elements are disposed in slots as close as possible to one another—that is, as close as possible to the air-gap, since they are in relative rotation. These conductors are interconnected in various ways, but as it is the purpose of our investigation to study these different methods of connection, we must not prejudge the question by assuming the machine to be connected in any particular way.

Finally, although in actual machines the air-gap surface is almost invariably cylindrical, we shall assume it to be plane, i.e. in the usual phraseology, that the machine is developed. Later we shall be able to formulate an exact and scientific definition of the dynamo-electric machine.

SECTION 2.—FUNDAMENTAL LAWS OF THE ELECTRIC MACHINE.

We have seen in Section 1 that omitting everything non-essential in our dynamo-electric machine, assuming a constant air-gap all round the periphery with all the reluctance of the machine concentrated in it, and developing the machine so that the gap surface is a plane instead of a cylindrical surface, it may be represented as in Fig. 1.

It consists of two magnetic elements separated by the air-gap and capable of relative motion along the axis of x. Each of these elements bears a number of electric conductors perpendicular to the plane of the paper or parallel to the axis of z, say. The axis of y may be taken perpendicular to the air-gap surface. We shall have very little occasion to use the axes of y and z but shall be constantly using that of x.

In [illegible] of the assumption of a constant air-gap all round, with all the reluctance of the machine concentrated in it, we get our first fundamental equation :—

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* [illegible]

$$B = \mu H \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

"Magnetic density is proportional to magnetomotive force at every point of time and space."

We here neglect saturation, of course, and μ must be taken to represent not the permeability but the permeance of unit area of the air-gap.

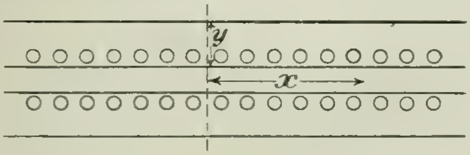


FIG. 1.

Our second fundamental equation is still more obvious if possible. The ampere-turns included within any stretch of the machine are a measure of the magnetomotive force H in accordance with the well-known equation :—

$$\text{ampere-turns} = \frac{10}{4\pi} H \text{ in electromagnetic units.}$$

The ampere-conductors are just twice the ampere-turns; hence they also are a measure of H. In "rational units," which we shall adopt, the constant $10/(8\pi)$ is got rid of and H is identical with the ampere-conductors.

Now it seems a truism to say that

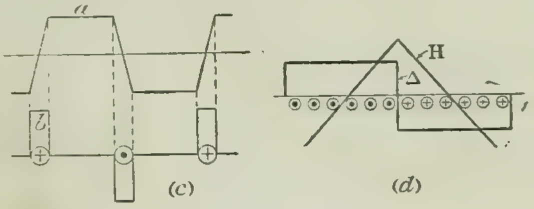
ampere-conductors per cm.
= current density per cm. of periphery.

Nevertheless, putting this into symbols we get the equation $dH_1/dx = \Delta_1$ for one member, and $dH_2/dx = \Delta_2$ for the other. If we use Δ_1 for the current density in the first member and H_1 to measure the ampere-conductors, dH_1/dx will be the ampere-conductors per cm.

Putting $H = H_1 + H_2$ to measure the resultant current density we get our second equation :—

$$dH/dx = \Delta_1 + \Delta_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

We can illustrate this equation by reference to particular cases.



(c) (d)

FIG. 2.

We see in Fig. 2 (*c*) that Δ is zero everywhere along the periphery except for certain small lengths where it has a constant value. It is shown at (*b*) in the form of a curve; (*a*) shows the magnetomotive force due to it, a square-topped wave as is obvious, having a constant value everywhere except where there is current. It is clear that the curve (*b*) is the slope or differential coefficient of curve (*a*), as stated by our equation.

Another example we may take from an ordinary continuous-current armature winding developed. The current density here is everywhere the same, so that it is represented by the square-topped curve marked Δ. H, however, rises to a maximum at the point where the current reverses, and then decreases. It is clear that the slope of H is constant, reversing after passing the apex, and hence that it is represented by a square-topped curve such as Δ.

A third fundamental equation is the following :—

Let E be the electromotive force per bar, i.e. potential difference between opposite ends of the same bar at the point x. Then the potential difference dE between adjacent bars will be equal to the time rate of change of magnetic density dB/dt between them multiplied by dx, or

$$dE_1/dx = dB/dt \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which may be read "Potential difference between adjacent bars = time rate of change of magnetic density between them."

If in addition one of the members be moving with respect to B at speed v, we shall have a further potential difference between adjacent bars equal in absolute units to v times the difference of density dB in the lines cutting them at the given instant.

Thus we get in this case

$$dE_2 = (dB/dt)dx + v(dB), \text{ or } dE_2/dx = dB/dt + v(dB/dx) \quad (4)$$

which may be read "Total potential difference between bars = time rate of change of magnetic density + v times the difference of magnetic density at each bar."

The equations which we have just deduced form a set of differential equations characterizing the dynamo-electric machine of the most general type, homopolar or multipolar.

In order to illustrate the meaning of these equations we may study a very important case by considering a flux wave stationary in space so that $dB/dt = 0$, while the two elements of the machine move past it with speeds v_1 and v_2 respectively. The equations then take the form :—

$$\frac{dH}{dx} = \Delta_1 + \Delta_2; \quad \frac{dE_1}{dx} = v_1 \frac{dB}{dx}; \quad \frac{dE_2}{dx} = v_2 \frac{dB}{dx}.$$

The last two equations may be integrated immediately, giving

$$E_1 = v_1 B + C_1 \text{ and } E_2 = v_2 B + C_2.$$

C_1 and C_2 relate to a possible superposed homopolar distribution and may be neglected.

In general such a wave of fixed form moving as a whole at a constant speed may be represented by an arbitrary Fourier series.

$$B = \Sigma_r B_r \sin\{r(mx - pt) + a\}$$
$$dB/dt = -p\,\Sigma_r r B_r \cos\{r(mx - pt) + a\}$$
$$dB/dx = m\,\Sigma_r r B_r \cos\{r(mx - pt) + a\}$$

so that $dB/dt = -(p/m)(dB/dx)$, and we can reduce our general equations to

$dH/dx = \Delta_1 + \Delta_2$;
$dE_1/dx = -(p/m)(dB/dx)$, or $E_1 = -(p/m)B + C$; and
$dE_2/dx = [v_2 - (p/m)(dB/dx)]$ or, neglecting arbitrary constants, $E_2 = [1 - v_2(m/p)]E_2$.

When [illegible] = 0, E = 0, which is another way of saying that when the [illegible] corresponding to E runs at the same speed as the flux there is no electromotive force in it.

Another general law arises from the fact that our machine is in part a moving body and therefore subject to the general laws of motion and in particular to the law that "action and reaction are equal and opposite."

The force acting on any conductor at the point x is $B\Delta\,dx$ in absolute units.

The total force, therefore, acting on any stretch of one element from zero to a, say, is

$$F = \int_0^a B\Delta\,dx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

F is usually given, being the load on the machine.

If F is equal and opposite to the force on the other member we get:

$$\int_0^a B\Delta_1 dx = -\int_0^a B\Delta_2 dx \text{ or } \int_0^a B(\Delta_1 + \Delta_2)dx = 0. \quad (6)$$

This, however, is not necessarily the case except for the whole machine.

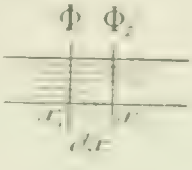


FIG. 3.

We may also express these equations in terms of the flux Φ through the core of our machine. Let us assume that the core length along the axis of Z is unity. Then the flux crossing the air-gap in the distance $x_1 - x$ is $\Phi_1 - \Phi$. But we know that the mean air-gap density B in any length $x_1 - x$ is the flux crossing the gap in that length divided by the length or

$$B = \frac{\Phi_1 - \Phi}{x_1 - x} = \frac{d\Phi}{dx} \text{ in the limit.}$$

We [illegible] H = [illegible]. Substituting these values in the equations given above and integrating the two E.M.F. equations, we get

[illegible] $E_1 = d\Phi/dt$; $E_2 = d\Phi/dt + v\,d\Phi/dx$;

a form of the equations which is often much more convenient than the original form.

Note to Section 2.—Maxwell's equations, in the form given by Heaviside, are

$$\text{curl}\,(\mathbf{E} - \mathbf{e}) = -\,d\mathbf{B}/dt$$

and curl $\mathbf{H} = \Delta$, the current density (a vector),

where $\mathbf{e}$ is the "motional" electromotive force $V\mathbf{q}\,\mathbf{B}$, and $\mathbf{q}$ is the velocity vector.

If we take the components of $\mathbf{H}$ and $(\mathbf{E} - \mathbf{e})$ parallel to x, y and z as H_1, H_2, H_3 and $(E-e)_1$, $(E-e)_2$, $(E-e)_3$ respectively, these equations in Cartesian co-ordinates will be as follows:—

$$\frac{dH_3}{dy} - \frac{dH_2}{dz} = \Delta_1; \quad \frac{dH_1}{dz} - \frac{dH_3}{dx} = \Delta_2; \quad \frac{dH_2}{dx} - \frac{dH_1}{dy} = \Delta_3,$$

and
$$\frac{d(E-e)_3}{dy} - \frac{d(E-e)_2}{dz} = -\frac{dB_1}{dt};$$

$$\frac{d(E-e)_1}{dz} - \frac{d(E-e)_3}{dx} = -\frac{dB_2}{dt};$$

$$\frac{d(E-e)_2}{dx} - \frac{d(E-e)_1}{dy} = -\frac{dB_3}{dt}.$$

Now if we take $H_1 = H_3 = 0$, or H parallel to the y axis, and $(E-e)_1 = (E-e)_2 = 0$, or $E - e$ parallel to the z axis, while $\mathbf{q}$ is parallel to x of length v, we get

$$dH/dx = \Delta; \quad d(E-e)/dx = dB/dt, \quad e = vB$$

so that $dE/dx = dB/dt + v\,dB/dx$.

Thus we have reproduced two of the equations which we obtained before, the third of course being obtainable by simply putting $v = 0$.

The second form of the equations in terms of Φ is analogous to Maxwell's form in terms of the vector-potential **A**. For the case where all the lines of force lie in one plane we may interpret **A** as the total number of lines of force surrounding a point.

SECTION 3.—GENERAL DISCUSSION OF THE FUNDAMENTAL EQUATIONS.

Collecting the results of the investigations of the last Section, we find ourselves in possession of the following equations :—

(1) $B = \mu H$. Equation of magnetic density.
(2) $dH/dx = \Delta_1 + \Delta_2$. Magnetomotive force equation.
(3) $dE_1/dx = dB/dt$. Stator E.M.F. equation.
(4) $dE_2/dx = dB/dt + v\,dB/dx$. Rotor E.M.F. equation.
(5) $F = \int_0^a B\Delta\,dx$. Force or torque equation.
(6) $\int_0^a B(\Delta_1 + \Delta_2)\,dx = 0$. Stating that action and re-action are equal and opposite.

Let us see what general conclusions we can draw from these equations—

(1) The differential equations are linear equations of the first order in x and t. These equations implicitly assume that the flux crossing the gap is due to the current distribution in the conductors. This is not true, for instance, in the homopolar machines, where Equation (2) takes the form $(dH - H_0)/dx = \Delta_1 + \Delta_2$.

Before we can deal usefully with these equations we must limit their generality by applying any further general conditions we can discover, necessitated by the nature of our problem. One such condition is the following :—

In practice the electric machine cannot be of infinite extent but must be annular, that is to say, if, starting from any given point we go round the circumference, we return again to the same point. In our development this fact will take the following form.

Starting from a point O (Fig. 4) and proceeding to the right we are compelled to assume that when we have travelled through a distance C equal to the circumference of our annular machine, every quantity mentioned in our equations resumes its original value—that is to say, the solution of our equations is periodic with respect to x and with period C. We only desire to study steady conditions, hence our quantities must be constant or periodic with respect to time also. There is no necessary relation whatever between the time periods and the space period, but the knowledge that the solution is periodic in both time and space enables us to effect a very important simplification.

Hence the general form of solution to which we are limited is

$$H = \Sigma_r a_r H_r \sin(\alpha_r x + \beta_r t + \gamma_r).$$

In the travelling wave discussed in Section 2, which moves at a fixed speed without change of shape, we had $\beta_r/\alpha_r = V$, a constant. In our present wave, however, there is no relation whatever between α_r and β_r and hence H consists of an unlimited number of waves the wave-lengths of which are sub-multiples of the circumference, but which travel at perfectly arbitrary speeds and are therefore entirely independent of one another.

Since we are permitted to assume that some or all of the lines of force crossing the air-gap are closed outside the system discussed, as in a homopolar machine, we cannot deduce the periodic nature of the solution from the fact that all magnetic lines must necessarily be closed. Excluding homopolar machines, however, a periodic solution would be necessitated by this fact also.

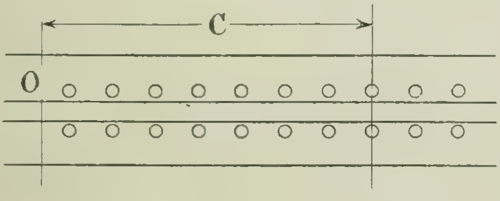


FIG. 4.

Since it may easily be proved that all the different components of the above general wave are independent unless in virtue of some special method of connecting the face-conductors, we may confine our attention in the first place to machines containing a single wave. Such machines may be broadly subdivided into

(1) Those containing a forced wave of flux density, etc., i.e. a wave whose wave-length, amplitude, and phase are determined by external circumstances—the interconnection of the face-conductors, the voltage, and frequency of supply, etc. Such machines form the vast majority of practical apparatus. It will be worth while to examine briefly how the wave-length is determined in such a type.

Instead of considering all the conductors as independent as we have hitherto done, we must now consider how they may be connected among themselves. They may be connected :—

(i) All in parallel, forming a squirrel-cage winding.

(ii) All in series, forming a ring winding. In this case the connection from one end of a conductor passes completely around the core carrying the flux to the beginning of the next conductor.

Both these methods of connection are independent of the wave-length of the flux wave. The former, however, is incapable of connection to an external circuit; we may therefore confine our attention to the latter.

If a periodic wave, such as we proved above necessarily exists in a dynamo-electric machine, is present in a core carrying a ring winding, points a wave-length apart will be at the same potential and may be joined by a conductor known as an "equalizer." When this has been done it is impossible for any wave to exist having a wave-length different from that determined by the points to which the equalizers are joined. Again, points half a wave-length apart may be joined to opposite sources of potential, constant or alternating, or points $1/n$th of a wave-length apart to sources of alternating potential differing in phase by $2\pi/n$.

From these methods of connection as fundamental we may derive by the theory of "armature windings" all the methods of winding employed in actual machines, practically all of which involve a forced wave of flux. The present paper, however, is devoted to an entirely different class of apparatus, namely,

(2) Those containing a free wave of flux, or in other words one whose wave-length is determined by internal reactions and hence is variable instead of being externally impressed.

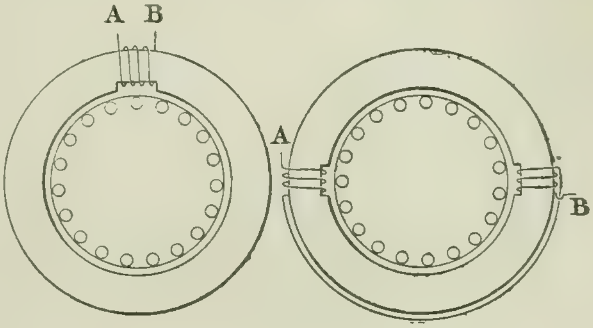


FIG. 5.

These waves can only occur in a type of winding in which the current in any bar is solely determined by the electromotive force in the same bar, and not by the electromotive force in a series of bars. The only type which fulfils this condition is the squirrel-cage type.

Hence the type of machine with which we shall deal will be one carrying a squirrel-cage winding on one member and on the other merely a primary winding concentrated at one point in the zone which we are studying, or at a limited number of points in the whole machine.

Such a machine is shown in Fig. 5. It consists of an ordinary squirrel-cage rotor and a primary member wound ring-wise around the core and concentrated in a single slot. The diameter of the apparatus is assumed to be sufficiently great to enable the disturbances on the positive side of the primary member to die away before passing sufficiently far around the machine to meet those on the negative side.

In the following sections a thorough study is made of such an apparatus and the influence of resistance, self-induction, and capacity in the rotor is worked out, as well as that of various secondary windings on the stator. Having done this we are in a position to consider the effects of two such coils wound in opposite phases on opposite ends of a diameter and carrying opposite currents. These are equivalent to a drum-wound coil; and having studied such a coil we can build up by the method of superposition the precise flux and current distribution due to a number of such coils, i.e. to a slotted stator such as is actually used in practice.

Occasionally we wish to consider what is taking place in a moving rotor at a point fixed in space rather than at a point fixed in the rotor. In this case it is helpful to consider the rotor as being ring-wound and connected to a commutator carrying a number of equally spaced brushes at distances apart which are small relative to the wave-length, in fact at distances which we denote by dx. These brushes are assumed to be short-circuited through a resistance, inductance, or capacity. It is shown below that there is a vital difference between the cases in which the inductance and capacity are assumed to be connected across the brushes and that in which they are contained in the secondary member and revolve with it.

Section 3.—Equations of Motion of the Waves due to Resistance, Inductance, and Capacity.

As above, we shall consider that on one element of our machine there is only a primary winding concentrated at one point, and consequently that the three differential equations deduced in Section 2 are reduced to two. These two equations are

$$dH/dx = \Delta\ ;\ \text{and}\ dE/dx = dB/dt + v(dB/dx).$$

We shall find it convenient as was done in Section 2 to express these equations in terms of the flux. We then get

$$(1/\mu)(d^2\Phi/dx^2) = \Delta\ ;\ \text{and}\ E = d\Phi/dt + v(d\Phi/dx) = d\Phi/dt + vB\ ;$$

or if we suppose both members to be wound

$$(1/\mu)(d^2\Phi/dx^2) = \Delta_1 + \Delta_2\ ;$$

$$E_1 = d\Phi/dt\ ;\quad E_2 = d\Phi/dt + v(d\Phi/dx).$$

There are two possible ways of treating each case. We have a primary and secondary member rotating relatively to one another. We may consider the secondary to be rotating and the primary to be stationary (Case 1), or vice versa (Case 2).

Let Z be the symbolical operator.

$$r + \mathrm{L\,D} + 1/\mathrm{K\,D},\ \text{where}\ \mathrm{D} = d/dt.$$

We may use Z_1 for the primary member and Z_2 for the secondary. Corresponding to the first method of treatment (primary stationary) we have the following differential equations:—

$$(1/\mu)(d^2\Phi/dx^2) = \Delta_1 + \Delta_2 = E_1 Z_1 + E_2 Z_2\ ;$$

$$E_1 = d\Phi/dt\ ;\ \text{and}\ E_2 = d\Phi/dt + v(d\Phi/dx).$$

These equations are partial differential equations, but we assume that every quantity follows a sine law in time, or in mathematical language, when x = constant, $\Phi = A\,\epsilon^{jpt}$. In this case we get, inserting $d/dt = jp$ [illegible] conditions. Substituting this value in our equations we find that they are reduced to ordinary differential equations, viz.

$$(1/\mu)(d^2\Phi/dx^2) = E_1 Z_1 + E_2 Z_2\ ;\ E_1 = jp\Phi\ ;\ E_2 = jp\Phi + v(d\Phi/dx),$$

t being eliminated.

If by means of some further relation between E and Δ such as is given above we eliminate both from our equations, we find invariably that the result is an ordinary differential equation of the second order in Φ whose solution is of the form $\Phi = \Phi_0\,\epsilon^{Sx + jpt}$. This gives $d\Phi/dx = S\,\Phi$, and permits us to eliminate d/dx from our equation as well, reducing it to an ordinary quadratic equation in complex quantities.

Hence we shall write

d/dx equivalent to $S = a + jm$, say,

and d/dt „ jp.

Corresponding to the second method of treatment we have the equations:—

$$(1/\mu)(d^2\Phi/dx^2) = \Delta_1 + \Delta_2 = E_1 Z_1 + E_2 Z_2\ ;$$

$$E_1 = d\Phi/dt - v(d\Phi/dx)\ ;\ \text{and}\ E_2 = d\Phi/dt.$$

If in Case 1 we assume the rotor to travel in the positive direction (v positive), we must now assume the stator to travel in the negative direction, as we have impressed on the whole system a rotation equal and opposite to that which the rotor had before.

Our limiting condition is now as follows:—

When $x = -vt\ ;\ \Phi = \Phi_0\,\epsilon^{jpt}$.

Hence, in general,

$$\Phi = \Phi_0\,\epsilon^{(a + jm)(x + vt) + jpt}.$$

Giving d/dx equivalent to $a + jm$, and d/dt to $jp + v(a + jm)$.

We may illustrate these results by the case of rotor resistance. Put $Z_1 = \infty$ (this corresponds to an unwound stator), and $Z_2 = r_2$. The equations then become:—

Case 1. $(r_2/\mu)(d^2\Phi/dx^2) = d\Phi/dt + v(d\Phi/dx)$, or, inserting the values of d/dx and d/dt,

$$(r_2/\mu)(a + jm)^2 = jp + v(a + jm).$$

Case 2. $(r_2/\mu)(d^2\Phi/dx^2) = d\Phi/dt$, or, inserting the values of d/dx and d/dt, $(r_2/\mu)(a + jm)^2 = jp + v(a + jm)$, which is identical with the above.

Now take the case of self-induction. $Z_1 = \infty$; $Z_2 = L_2(d/dt)$.

Case 1. $$\frac{L_2}{\mu}\cdot\frac{d}{dt}\cdot\frac{d^2\Phi}{dx^2} = \frac{d\Phi}{dt} + v\frac{d\Phi}{dx}.$$

$$(L_2\,jp/\mu)(a + jm)^2 = jp + v(a + jm).$$

Case 2. $$\frac{L_2}{\mu}\cdot\frac{d}{dt}\cdot\frac{d^2\Phi}{dx^2} = \frac{d\Phi}{dt}.$$

$$(L_2/\mu)\{jp + v(a + jm)\}(a + jm)^2 = \{jp + v(a + jm)\}$$

or $$(L_2/\mu)(a + jm)^2 = 1.$$

It will be seen that the equations obtained from Case 1 and Case 2 are entirely different. The reason for this is as follows:—

Case 1 ($d/dt = jp$) implicitly assumes that the self-induction L_2 always operates on a constant frequency, while Case 2 permits the frequency to vary with the speed. The difference between these two cases may be illustrated by reference to the ordinary polyphase induction motor.

Suppose the rotor of such a motor to contain no resistance but merely self-induction. As the speed rises from standstill the rotor E.M.F. falls in proportion to the frequency. The rotor reactance also falls in exact proportion to the frequency, so that the rotor current remains absolutely constant and independent of the speed. If, however, the said rotor is fitted with a commutator and the brushes resting on this are closed through a reactance the case is quite altered. Since the frequency of the current through the reactance is always equal to the line frequency there is no change in the reactance with the speed, and since the rotor E.M.F. falls with the speed as before, the rotor current now falls with the rotor E.M.F. instead of remaining constant. This case is merely a simple example of that illustrated by the two differential equations and serves to explain the difference between them quite clearly.

Case 2, therefore, is that in which the self-induction is connected direct to the rotor and revolves with it. It may be shown independently that this equation applies even in the limiting case of continuous current. Case 1 refers to a machine fitted with a commutator, the self-induction being outside the commutator and fed with currents at full frequency. Case 2 is therefore correct for our purposes.

Now take the case of capacity. We have

$$Z_1 = \propto, \text{ and } Z_2 = 1/K D.$$

Case 1 gives $\frac{1}{\mu} \cdot \frac{d^2 \Phi}{d x^2} = K \frac{d}{d t} \left(\frac{d \Phi}{d t} + v \frac{d \Phi}{d x}\right),$

or substituting,

$$[1/(K \mu)] (a + j m)^2 = j p [j p + v (a + j m)].$$

Case 2 gives $(1/\mu) (d^2 \Phi/d x^2) = K (d^2 \Phi/d t^2),$

or $[1/(K \mu)] (a + j m)^2 = [j p + v (a + j m)]^2,$

two results which again are quite different.

Confining ourselves to Case 2 we get the following three equations :—

(*a*) *Resistance.* $(1/\mu) (a + j m)^2 = [j p + v (a + j m)] (1/r_2).$

(*b*) *Self-induction.* $(1/\mu) (a + j m)^2 = \frac{j p + v (a + j m)}{L_2 [j p + v (a + j m)]}.$

(*c*) *Capacity.* $(1/\mu) (a + j m)^2 = \frac{j p + v (a + j m)}{1/K [j p + v (a + j m)]}.$

The various cases may thus be obtained from the general equation

$$\frac{1}{\mu} \cdot \frac{d^2 \Phi}{d x^2} = \frac{d \Phi}{d t} \Big/ \left[r + L \frac{d}{d t} + \frac{1}{K (d/d t)}\right]$$

by putting $d/d t = j p + v (a + j m)$, and $d/d x = (a + j m)$.

Case 1 gives

$$\frac{1}{\mu} \cdot \frac{d^2 \Phi}{d x^2} = \left(\frac{d \Phi}{d t} + \frac{v \, d \Phi}{d x}\right) \Big/ \left[r + L \frac{d}{d t} + \frac{1}{K (d/d t)}\right]$$

with $d/d t = j p$ and $d/d x = a + j m$.

If now we put $Z_2 = \infty$, or in other words open-circuit the rotor, our differential equations reduce to two instead of three, since all our windings are now on the same member.

Our differential equations now are $(1/\mu) (d^2 \Phi/d x^2) = \Delta$, and $E = d \Phi/d t$, and we shall make use of Case 1 (primary stationary).

(*a*) Putting $Z_1 = r_1$, we get $(1/\mu) (d^2 \Phi/d x^2) = (1/r_1) (d \Phi/d t)$, or substituting, $(r_1/\mu) (a + j m)^2 = j p$.

(*b*) Putting $Z_1 = L (d/d t) = j L p$ we get $(L_2/\mu) (a + j m)^2 = 1$ on substituting.

(*c*) Putting $Z_1 = \frac{1}{K (d/d t)} = \frac{1}{K j p}$, we get $\frac{1}{K \mu} \cdot \frac{d^2 \Phi}{d x^2} = \frac{d^2 \Phi}{d t^2}$,

or $S^2/(K \mu) = (j p)^2$.

To recapitulate, we have now derived the following equations, where $S = (a + j m)$ if there are no windings except the primary on the stator.

(*a*) $(r_2/\mu) S^2 = j p + v S.$

(*b*) $(L_2/\mu) (j p + v S) S^2 = (j p + v S).$

(*c*) $\frac{S^2}{K \mu (j p + v S)} = j p + v S.$

It will be noted at once that all these equations are quadratics in S, the quadratic arising of course from the fact that the differential equations are of the second order. It will be useful, then, to attempt a solution of the general quadratic in complex quantities.

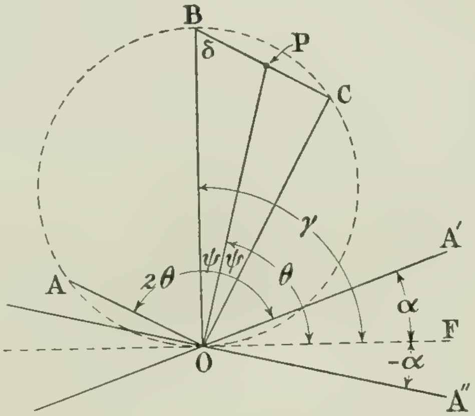


FIG. 6.

In the general equation, $a S^2 + b S + c = 0$, we can always multiply throughout by any complex number in such a way that the coefficient b becomes a pure real. We shall, therefore, for the future assume that b is a real or scalar, while a and c are any two arbitrary vectors.

Let $O A = a S^2 = a r^2 \operatorname{cis} 2 \theta \operatorname{cis} \alpha$

$A B = b S = b r \operatorname{cis} \theta$

$B O = c = c \operatorname{cis} \gamma$ (see Fig. 6)

$O A' = a \operatorname{cis} \alpha$

We are here using $\operatorname{cis} \alpha$ as an abbreviation for $\cos \alpha + j \sin \alpha = e^{j \alpha}$.

Draw $O A' = a \operatorname{cis} \alpha$, $O B = - c \operatorname{cis} \gamma$, an arbitrary vector $O P = r \operatorname{cis} \theta$, and another $O A = a r^2 \operatorname{cis} (2 \theta + \alpha)$. Draw through B a line B P parallel to O A.

Then if $\delta =$ angle O B P and $\psi =$ angle P O B

$$\delta = 2 \theta + \alpha - \gamma, \text{ and } \psi = \gamma - \theta$$

$$2 \psi + \delta = 2 \gamma - 2 \theta + 2 \theta + \alpha - \gamma$$

$$= \gamma + \alpha, \text{ that is, a constant.}$$

If, therefore, we draw a line OC making with OB an angle COB = [illegible], it follows that the angle BCO is constant and the point C therefore moves on a circle passing through O and B. If we now draw a line OA making an angle [illegible] with OB, it follows that the circle must touch this line, which gives us a construction whereby we may draw it conveniently.

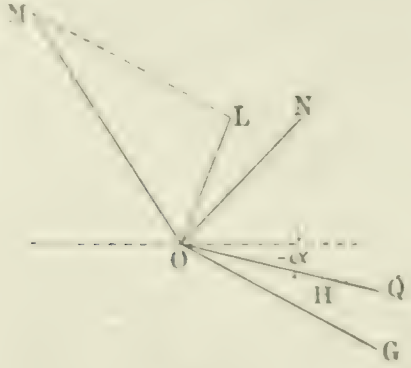


FIG. 7.

By means of this diagram we may plot the locus of P [illegible]

If, therefore, we have some further means of ascertaining which value of θ satisfies the equation, the above diagram will give the value of r corresponding to it.

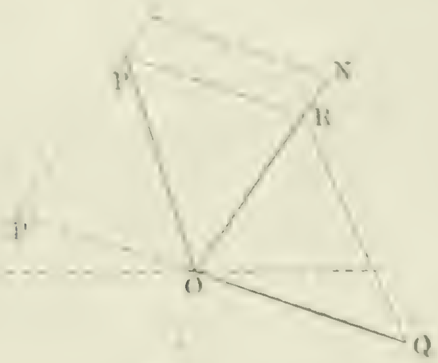


FIG. 8.

[illegible]

or [illegible]

or [illegible]

[illegible]

[illegible]

We shall now endeavour to construct the vector [illegible]

Remembering that b is a pure scalar we have (see Fig. 7)

[illegible] = OQ, [illegible] = OH, [illegible] = OL,

[illegible] = OM, [illegible] = ON.

Now in the previous diagram we had $OP = bS$, and since b is a pure scalar the direction of b times ON is the same as that of ON. In terms of the vectors in our diagram [illegible] now reads OP + OQ = [illegible] ON = OR (see Fig. 8), and hence since OQ is constant the locus of P must be the straight line PP′.

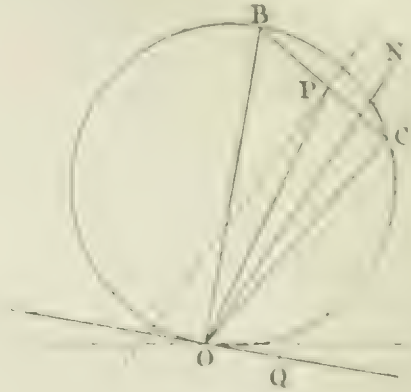


FIG. 9.

Combining this result with the diagram previously obtained based on the circle, we obtain the final graphical solution of our equation (Fig. 9).

OP must satisfy two conditions :—

(1) It must lie on a straight line parallel to ON.

(2) It must lie on the locus which may be traced by means of the circular construction.

The straight line cuts the locus in two points and hence we obtain our two roots.

SECTION 5.—SOLUTIONS OF THE EQUATIONS OF MOTION.

In the present section we shall endeavour to obtain and interpret the solutions of the equations formulated above. At the end of Section 4 we obtained a general solution of the quadratic equation in complex quantities by means of a graphical construction. In the present section, however, we shall usually adopt a method which consists essentially in eliminating v from the equations by some convenient means.

Starting with the equation [illegible] which relates to the case of rotor resistance only, we resolve it into real and imaginary components :—

[illegible] . . . (1)

[illegible] . . . (2)

Put $a = S\cos\theta$ and $w = S\sin\theta$, and we get

[illegible]

Substituting in (1) we get

[illegible]

or [illegible]

Another important conclusion is the following :—

— [illegible] the [illegible] speed of the wave

Hence Equation (2) can be written (dividing by m)

$$(2\,r_2/\mu)\,a = -(-p/m - v) = -(v_0 - v) = -v_1$$

where v_1 is the slip velocity. In words this equation may be interpreted :—

The decrement is proportional to the slip velocity.

Another deduction from the same equation is as follows :—

$$(2\,r_2/\mu)\,[a - v\,\mu/(2\,r_2)]\;m = p.$$

$$\therefore\;[a - v\,\mu/(2\,r_2)]\;m = p\,\mu/(2\,r_2).$$

If we put $x = a - v\,\mu/(2\,r_2)$ and $m = y$ we get $x\,y = p\,\mu/(2\,r_2)$.

If we put $r_2/\mu = c$, we get $x\,y = p/(2\,c)$, that is, the equation of an hyperbola.

Moreover $x = (p/m)\,[\mu/(2\,r_2)] = -v_0/(2\,c)$. Hence x is proportional to the synchronous speed.

Now plot the two equations

$$S^2 = (p/c)\cot\theta \quad . \quad . \quad (1) \quad \text{and} \quad x\,y = p/2\,c \quad . \quad . \quad (2)$$

on the same sheet. If we do this the abscissa of curve (1) will be $\mathrm{Y\,P} = a$, and that of curve (2) will be

$$\mathrm{Y\,P_1} = a - v\,\mu/(2\,r_2) = a - v/(2\,c).$$

$$\therefore\;\mathrm{Y\,P} - \mathrm{Y\,P_1} = -v\,\mu/(2\,r_2) = -v/(2\,c) = \mathrm{P\,P_1},$$

or $\mathrm{P\,P_1}$ is proportional to the speed.

Summing up these results we have

Fig. 10. $\mathrm{Y\,P_1} = -v_0/(2\,c) =$ (− synchronous speed).

,, $\mathrm{P\,P_1} = -v/(2\,c) =$ actual speed.

,, $\mathrm{Y\,P} = \mathrm{Y\,P_1} - \mathrm{P_1\,P} = -(v_0 - v)/(2\,c)$
$= -v_1/(2\,c) =$ slip velocity.

$\mathrm{O\,P} =$ current ; $\mathrm{O\,P^2}$ or $\mathrm{U\,T} =$ torque.

Since the torque is proportional to B^2 it is proportional to $\mathrm{O\,P^2} = S^2 = (p/c)\cot\theta$. Cot θ is proportional to U T.

Since throughout these investigations we have taken x as parallel to the real axis, we have $E = j\,p\,\Phi$ parallel to O Y, and hence the angle $\mathrm{P\,O\,Y} = \phi$, the angle of phase difference.

These investigations relate to the occurrences on one side only of the primary coil. Both sides must be considered.

In this case we may consider that on one side of the exciting coil the speed is $+v$, and on the other $-v$.

In this case the total current in the exciting coil $= \mathrm{O\,P} + \mathrm{O\,P_2}$. We have

$$\mathrm{P\,P_1} = \mathrm{P_1\,P_2}. \quad \mathrm{O\,P_1} = \mathrm{O\,P} + \mathrm{P\,P_1} = \mathrm{O\,P_2} - \mathrm{P_2\,P_1}.$$

$$\mathrm{O\,P} + \mathrm{O\,P_2} = 2\,\mathrm{O\,P_1} \text{ (see Fig. 10),}$$

and since $\mathrm{O\,P_1}$ moves on an hyperbola, so does the current in the exciting coil.

It may be of interest to prove that at the maximum point of the curve $\theta = 45°$.

The shape of the curve is as shown in the figure. Transforming the equation

$S^2 = k\cot\theta$ to Cartesian co-ordinates,

it becomes $x^2 + y^2 = k\,(S\cos\theta)/(S\sin\theta) = k\,x/y$,

or $x^2\,y - k\,x + y^3 = 0$, that is, a quadratic in x.

The value of y for which the two roots of this quadratic are equal is clearly the maximum value.

$$x = \frac{k \pm \sqrt{(k^2 - 4\,y^4)}}{2\,y}.$$

When $2\,y^2 = k$ or $y = \sqrt{(k/2)}$ the two roots are equal.

,, $\theta = 45°$, $\cot\theta = 1$ and $x = y$.

The equation then becomes $S^2 = x^2 + y^2 = 2\,y^2 = k$, the result just obtained. Hence y is a maximum when $\theta = 45°$.

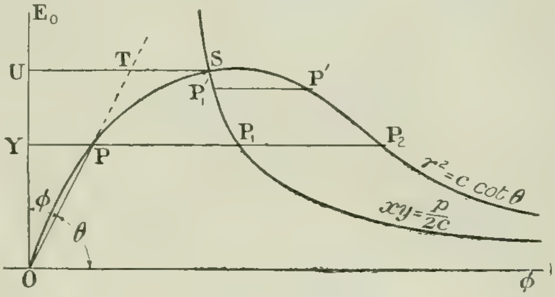


FIG. 10.

Besides the construction given above for the speed, another may be very easily deduced from the E.M.F. triangle, which as it is of very general application it may be of interest to give.

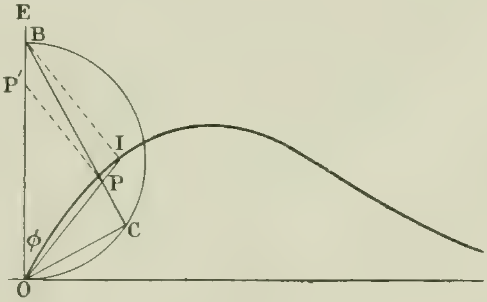


FIG. 11.

We gave above a general solution of the quadratic equation in complex quantities for any values of the coefficients. We have now to consider what are the values of the coefficients in the case we are considering.

The equation which results from the differential equation in the case of rotor resistance is

$$(r_2/\mu)\,S^2 - v\,S - j\,p = 0.$$

Hence $c = -j\,p$; $a = r/\mu$; $b = -v$ (see page 455) ; and following the construction we must draw our circle passing through the extremity of $\mathrm{O\,B} = j\,p$ (see Fig. 11) and touching the real axis (since $a = 0$). Since O B is at right angles to the real axis it is a diameter of the circle. We saw in general that $\mathrm{O\,P} = b\,S = -v\,S$ in this case. Hence our speed construction will be as follows :—

Draw the locus of the current vector $S^2 = (p/c)\cot\theta$ as before, and also the circle as above. Corresponding to any current vector O I draw a line O C to cut the circle, [illegible] with O E. Join B C; P will be the point where B C cuts O I. Then O P/O I = v.

In order to read off v on a fixed line all we have to do is to join E to some fixed point such as B and draw through P a line P P' parallel to I B. Then O P'/O B = O P/O I, and consequently O P is a measure of the speed to such a scale that O B = 1.

This speed construction is perfectly general and applicable to any case in which the coefficient of S is proportional to v.

We must now consider the effect of stator resistance, inductance, and capacity, combined with rotor resistance.

Taking the case of inductance first and supposing the primary to be stationary, we have

[illegible]

[illegible]

or $$(r_2/\mu)\,S^2 = r_2/L + jp + vS.$$

In the case of stator capacity we have

[illegible] $= -r_2 K p^2 + jp + vS.$

And in the case of stator resistance

[illegible]

[illegible]

The sole influence therefore of stator resistance, inductance, and capacity is to vary the absolute term of the quadratic either in magnitude only or in both magnitude and direction.

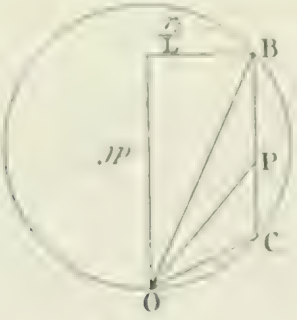


Fig. 12.

Taking the case of resistance first, it is clear that since we have merely multiplied the absolute term by $(1 + r_2/r_1)$ the resultant locus will be unchanged in shape, but merely multiplied by the same quantity, viz. $(1 + r_2/r_1)$.

Hence the locus of the current vector will now be :—

[illegible] instead of

[illegible] as before.

Hence the size of the diagram is increased but its shape is unchanged.

Returning to the cases of self-induction and capacity the equations we have just obtained are

[illegible]

[illegible]

In these two equations we have

[illegible]

[illegible]

Hence the diagrams are as follows :—

The real axis is still a tangent to the circle in both cases; O B is, however, no longer a diameter but lags or leads relatively to its former position. This is illustrated in Fig. 12 for the case of self-induction, and Fig. 13 for capacity.

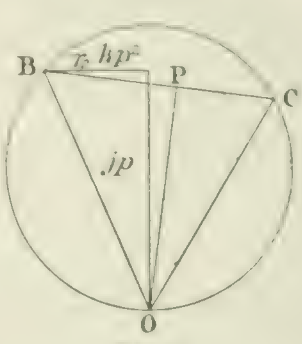


Fig. 13.

We may, of course, discuss the matter by eliminating v as we did before. Referring back to the equation given above, we see that we now have in the case of self-induction

$$(r_2/\mu)(a^2 - m^2) = va + r_2/L, \text{ and } (r_2/\mu)\,2am = p + vm.$$

The second of these equations remains the same in all cases.

Put $a = S\cos\theta$, and $m = S\sin\theta$. We then get

$$v = 2(r_2/\mu)S\cos\theta - p/S\sin\theta,$$

and $$va = 2(r_2/\mu)S^2\cos^2\theta - p\cot\theta,$$

thus [illegible]

$$\therefore \quad S = (p\mu/r_2)\cot\theta + r_2/L.$$

In the case of capacity we merely have $-r_2Kp^2$ instead of r_2/L, and we therefore get

$$S = (p\mu/r_2)\cot\theta - r_2Kp^2.$$

In the former case if $S = 0$ we have $\cot\theta_1 = r_2/(Lp\mu)$. S now becomes zero for some definite value of θ different from 90° and the diagram has the shape shown in Fig. 14a when we use self-induction in the stator. If condensers are used we obtain the shape shown in Fig. 14b, and a, the decrement, vanishes for some finite value of the current. The torque is still proportional to S^2.

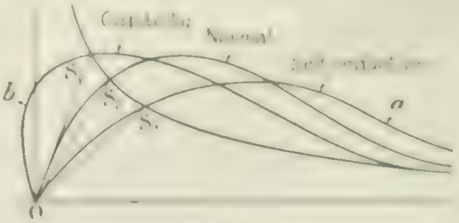


Fig. 14.

Since the decrement is still proportional to the slip it follows that at the point of unity power factor the machine is running in synchronism. Beyond that point it is running above synchronism and there will be an increment instead of a decrement. If we complete the discussion of this case by considering a second primary coil at $x = c$ we shall find that the machine on the whole is now a generator.

We saw that stator self-induction or capacity produced no effect on the equation determining the slip. This equation, viz. $(r/\mu)\, 2\, a\, m = p - v\, m$, may be written $y\,[x - v/(2\, c)] = p/(2\, c)$, which represents an hyperbola. Hence the speed construction remains the same in both these cases. In any case, no matter what the angle of lag at starting, the hyperbola passes through the point of the curve corresponding to $v = 0$. As the hyperbola is independent of the stator self-induction or capacity it is the locus of the starting current when we vary the latter. Since the hyperbola is the locus of the starting current it is clear that the angle of lag at starting is affected by the use of condensers (S_1) or self-induction (S_3). In the former case it is reduced and in the latter increased.

Having now considered the case of rotor resistance either alone or combined with resistance, self-induction, or capacity in the stator, we may now consider the cases of rotor self-induction and capacity.

The case of rotor self-induction is very simple. We have already derived the equation $(L_2/\mu)\, S^2 = 1$ for this case; whence it follows that $S = a = \sqrt{(\mu/L_2)}$ at all speeds. The apparatus will therefore absorb a constant current lagging 90° behind its electromotive force at every speed, there being no "phase splitting" and hence no torque.

Such an apparatus is thus only suitable for purposes of neutralization and not for power. Hence, even if we supply a machine having merely self-induction on the rotor with a stator winding having resistance or capacity to produce phase-splitting or even a uniform polyphase winding, no torque can result. Thus this simple investigation disposes of a whole class of cases.

In the case of condensers the equation we derived was $1/(K\,\mu)\, S^2 = (j\, p + v\, S)^2$. Putting $1/(K\,\mu) = v_0^2$ and transposing, we get

$$(v_0^2 - v^2)\, S^2 - 2\, v\, j\, p\, S - (j\, p)^2 = 0.$$

Solving this quadratic in S we get

$$S = j\, m = \frac{v\, j\, p \pm \sqrt{[- v^2 p^2 - p^2 (v_0^2 - v^2)]}}{v_0^2 - v^2},$$

or
$$S = j\, p \left(\frac{v \pm v_0}{v_0^2 - v^2}\right) = \frac{j\, p}{v_0 \pm v}.$$

At zero speed we have a current $O\, S_0 = j\, p/v_0$. As the speed rises the current falls if the rotor revolves in the same direction as the field, and rises if the rotor revolves in the opposite direction. At the same time m the number of poles per unit length varies proportionally to the current. This is the Doppler effect as it appears in our case.

We have seen that the case of rotor condensers gives rise to an interesting result, viz. an analogue of the Doppler effect. Let us, therefore, now attempt to investigate the case of rotor condensers and stator resistance, inductance, or capacity.

(1) *Stator self-induction.*—Putting $Z_1 = L\,(d/d\,t)$ and $Z_2 = 1/(K\,D)$, we get

$$\frac{d}{d\,t} \cdot \frac{1}{\mu} \cdot \frac{d^2 \Phi}{d\,x^2} = K \frac{d^3 \Phi}{d\,t^3} + \left(\frac{d\,\Phi}{d\,t} - v\,\frac{d\,\Phi}{d\,x}\right)\frac{1}{L}.$$

Remembering that $d/d\,t = j\,p + v\,S$, in Case II above we get on substituting

$$1/(K\,\mu)\,(j\,p + v\,S)\,S^2 = (j\,p + v\,S)^3 + j\,p/(L_1\,K).$$

(2) *Stator resistance.*

$$\frac{r_1}{\mu} \cdot \frac{d^2 \Phi}{d\,x^2} = K\, r_1 \frac{d^2 \Phi}{d\,t^2} + \left(\frac{d\,\Phi}{d\,t} - v\,\frac{d\,\Phi}{d\,x}\right)$$

$$\therefore \quad \frac{r_1}{K\,\mu}\, S^2 = r_1\,(j\,p + v\,S)^2 + j\,p/K.$$

(3) *Stator capacity.*

$$\frac{1}{\mu} \cdot \frac{d^2 \Phi}{d\,x^2} = K_1 \frac{d^2 \Phi}{d\,t^2} + K_1 \frac{d}{d\,t}\left(\frac{d\,\Phi}{d\,t} - v\,\frac{d\,\Phi}{d\,x}\right)$$

$$\therefore \quad \frac{1}{K_1\,\mu}\, S^2 = (j\,p + v\,S)^2 + \frac{K_1}{K_2}(j\,p)\,(j\,p + v\,S).$$

Expanding the three equations they may be written as follows, puting $1/(K\,\mu) = v_0^2$.

(1) *Resistance.*

$$(v_0^2 - v^2)\,S^2 - 2\,j\,p\,v\,S + p^2\,[1 + 1/(j\,K\,p\,r_1)] = 0.$$

(2) *Capacity.*

$$(v_0^2 - v^2)\,S^2 - j\,p\,v\,S\,(2 + K_1/K_2) + p^2\,(1 + K_1/K_2) = 0.$$

(3) *Inductance.*

$$(v_0^2 - v^2)\,v\,S^3 + (v_0^2 - 3\,v^2)\,j\,p\,S^2 - 3\,j\,p^2\,v\,S - j\,p\,(1/L\,K - p^2) = 0.$$

The first two of the above equations may be treated by the same method as that applied in the case of rotor capacity only, viz. by solving the quadratic in S. By this means we get the following results :—

$$(1)\ S = j\,p\,\frac{v \pm \sqrt{\{v^2 + (v_0^2 - v^2)\,[1 + 1/(j\,K\,p\,r_1)]\}}}{v_0^2 - v^2}$$

and

$$(2)\ S = j\,p\,\frac{v(1 + K_1/K_2) \pm \sqrt{\{v^2(1 + K_1/K_2) + (v_0^2 - v^2)(1 + K_1/K_2)\}}}{v_0^2 - v^2}$$

Part 2.

SOME MECHANICAL ANALOGIES.

From the mathematical discussions in Part 1 it is very difficult to form a clear physical idea of the phenomena actually taking place—at any rate the author finds it so. On the other hand it is inadvisable, from the point of view of clearness, to burden a mathematical investigation with long physical explanations. It has therefore been decided to take the subject up afresh from the physical standpoint and to endeavour to give a clear account of it as free from mathematics as possible, referring the reader for proofs to Part 1 of the paper where necessary.

Let us first consider under what conditions it is possible [illegible] conductors on an electric machine to experience a [illegible]. There is first of all the ordinary case [illegible] "compensated" machines in which conductors that lie opposite to one another on the two members carry equal and opposite currents except for a small component which serves for magnetizing. In this case the force on each conductor is $\int (\mathrm{B}\,\Delta\,dx)$ and B and Δ are entirely independent of one another.

In certain types of machines, such as continuous-current and synchronous machines, B and Δ are not independent, it being possible to express Δ as a function of B. In these machines there is no neutralizing winding, the winding on one member—the field—being concentrated in one large slot per pole. An attempt is usually made to reduce the distortion or influence of Δ on the distribution of flux density B as much as possible by exaggerating the field ampere-turns relatively to those of the armature, and by employing long air-gaps, high saturations, etc. In this manner these cases are made to correspond approximately to those in which a neutralizing winding is employed. An entirely different treatment, however, will be found below in which the force is expressed in terms of the distribution of the field.

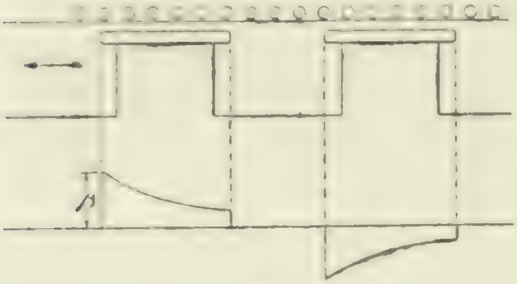


Fig. 15.

As an illustration of this we may apply the investigations of Part 1 to the only case in which windings concentrated in a single slot are widely used in practice, viz. that of the synchronous and continuous-current machines mentioned above. To the case of the synchronous alternator these investigations are directly applicable if we consider a machine having as many phases as there are slots per pole, each phase being closed through a resistance load. We may have the exact case discussed in Part 1 of a concentrated "primary" winding carrying continuous current in the rotor and "secondaries" short-circuited through resistance only. If therefore we put $p = 0$ in our previous equations (page [illegible]) we shall get a solution applicable to this case, viz. [illegible], giving $\mathrm{B} = \mathrm{B}_0\,\epsilon^{[illegible]}$. Thus the flux density in the pole-face is distorted by the action of the armature currents and is [illegible] in accordance with an exponential curve with an increment [illegible] and whose increment is proportional to the speed. We shall see from the principles developed below, that when there is an increment in the direction of motion the torque produced is opposed to the direction of motion, as of course is the case in the apparatus we are discussing. In fact since B is a function of x the torque of the machine can be expressed purely in terms of B, and the methods of regarding the question which are discussed below apply in their entirety.

To understand this clearly it will be best to start by considering a single conductor carrying a current and lying in a magnetic field.

Let this resultant field, for instance, be compounded of an original field and the field due to the current. The field will be strengthened on one side of the current—that on which the magnetomotive force H due to the current assists the original field—and weakened on the other where they are opposed (Fig. 16). The net result is a force moving the conductor into the direction of the weaker field. The amount of this force is equal to the difference of magnetic energy density $\frac{1}{2}\mu\,\mathrm{H}^2$ on opposite sides of the conductor. A more usual expression for this force is $\mathrm{F} = \mathrm{B}\,\Delta$. Since as we saw above $\Delta = d\,\mathrm{H}/dx = (1/\mu)\,d\,\mathrm{B}/dx$ in the dynamo-electric machine, we have:—

Force on a system of conductors extending from $x = \mathrm{A}$ to $x = \mathrm{B}$

$$= \frac{1}{\mu}\int_{\mathrm{A}}^{\mathrm{B}} \mathrm{B}\,(d\,\mathrm{B}/dx)\,dx = \frac{1}{2\mu}(\mathrm{B}_{\mathrm{B}}^2 - \mathrm{B}_{\mathrm{A}}^2) = \tfrac{1}{2}\mu(\mathrm{H}_{\mathrm{B}}^2 - \mathrm{H}_{\mathrm{A}}^2),$$

the same as before, since $\mathrm{B} = \mu\,\mathrm{H}$.

The expression $\mathrm{F} = \frac{1}{2\mu}(\mathrm{B}_{\mathrm{B}}^2 - \mathrm{B}_{\mathrm{A}}^2)$ may also be written in the form $\mathrm{F} = \mathrm{B}\,\Delta$, for

$$\frac{1}{2\mu}(\mathrm{B}_{\mathrm{B}}^2 - \mathrm{B}_{\mathrm{A}}^2) = [(\mathrm{B}_{\mathrm{B}} - \mathrm{B}_{\mathrm{A}})/\mu]\,[\tfrac{1}{2}(\mathrm{B}_{\mathrm{B}} + \mathrm{B}_{\mathrm{A}})]$$

= current between B and A multiplied by the mean density.

If, therefore, we can by any means whatever set up a difference of magnetic densities on opposite sides of a current-carrying conductor there will be a force acting on the conductor. Since the force is proportional to the square (and not to the first power) of the density, the direction of the lines of force is immaterial—i.e. whether upwards or downwards in Fig. 16.

Now suppose a number of conductors to be arranged on the periphery of an electric machine and consider the torque on the whole set of conductors in various instances. If the distribution of B is periodic there can be no resultant torque, for if the torque on conductors (1) and (2), say, has a certain direction, that on conductors (3) and (4) will be in the opposite direction.

If B, however, starting from a certain point continually gets less and less following an asymptotic curve the force on every conductor will have the same direction. If this curve, however, crosses the zero line, the intensity of B increasing in the opposite direction, the force will reverse at the point where the curve crosses the zero line.

Some possible distributions of density are shown in the table below, together with a note of the force given by them.

(1) *Asymptotic curve.*—The force on every conductor is in the same direction.

(2) *Sine wave with decrement.*—While the force on every conductor is not in the same direction, the average force over a complete period always has the same direction.

(3) *Sine wave without decrement.*—There is no resultant force over a complete number of periods.

(4) *Straight line.*—The force reverses where B reverses. The direction of the resultant force depends on whether the positive or negative flux is the greater.

It is important to notice in cases in which we have two conductors close together, as on the rotor and stator of a dynamo-electric machine, that that force referred to is the force on both conductors considered as a single system. For instance, in the case given in Fig. 21 in which the stator and rotor currents are equal and opposite, there may be a uniform field and consequently no resultant force and yet large relative forces between the rotor and stator conductors.

This, however, is an essentially different case though it is the principle on which the torques of almost all existing machines depend. For instance, if we have two equal and opposite currents in a magnetic field the distribution of flux which they will produce is shown in Fig. 17, if the line joining them is parallel to the original direction of the flux. A couple will then be exerted tending to turn the conductors into such a position that the lines threading them will be as few as possible. If, however, they are mechanically constrained so that they cannot move in the manner indicated, one of the conductors will continue to be urged to the right and the other to the left. If we have a succession of such pairs as shown in Fig. 21 the lines will take the form shown and equal and opposite forces will be exerted on the two sets.

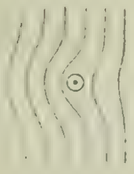


FIG. 16.

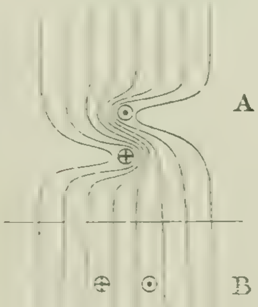


FIG. 17.

In the case in which B is a function of the time, and thus admits of a mean value, i.e. is a periodic function, we have

$$\text{Mean of } (B_B^2 - B_A^2) = \text{Mean of } B_B^2 - \text{Mean of } B_A^2.$$

Hence in this case

$$\text{Mean force} = \frac{1}{2\mu}(\text{difference in mean square densities}).$$

Hence in order that the mean force on every conductor shall be in the same direction it is only necessary that the mean distribution of density shall be asymptotic. For instance, if the density is distributed as a travelling wave with decrement, that is, $B = B_0 e^{ax} \sin(pt - mx)$, then for any value of x such that $mx = a$, the mean value of $B^2 = \frac{1}{2} B_0^2 e^{2ax}$, since the mean of $\sin^2(pt - a) = \frac{1}{2}$, independently of the value of a. Thus such a travelling wave would give a mean force having the same direction for every conductor.

The theorem that the force on a body is equal to the difference of energy densities on either side of it is in no way peculiar to electricity but is a general theorem of mechanics. For instance, the average force per square inch on a partition between two fluids of different levels is proportional to the mean pressure, i.e. to the mean density of potential energy on the two sides. In a vibrating cord or chain the force between adjacent links is proportional to the difference between the kinetic energies of the links.

We have now to consider what means may be adopted in the various electric, hydraulic, etc., cases to realize a distribution of magnetic, potential, or kinetic energy, etc., adapted to give a steady force.

We have seen that if we can by any means produce a travelling wave moving in the direction in which we wish the force to be, we can obtain such a force if the wave has a decrement in the direction of travel, but not otherwise. If there is no decrement there will be no mean force, while if there is an increment there will be a force opposed to the direction of travel. Our inquiry then resolves itself into a study of the means of production of such waves.

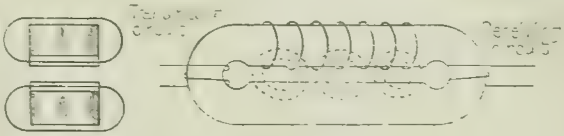


FIG. 18.

Two distinct types of electromagnetic transmission exist whereby energy may be transmitted from one place to another along a line :—

(1) The type so much studied in connection with cables, etc., in which the current flows along the axis of x and the magnetic lines form closed rings round it. The electrostatic lines are radial near the cable, and if it is sufficiently long both ends rest on different parts of it, these parts being a half wave-length apart. Energy flows along the cable in the form of waves at a definite speed, as has been very thoroughly discussed by Kelvin, Heaviside, Pupin, and many others.

(2) It has not hitherto been realized that there is another type of power-transmission line possible in which the functions of the electrostatic and magnetic lines in the above example are interchanged.

Consider a closed iron core (Fig. 18) the two limbs of which A and B are separated by a certain air-gap and carrying at least two electric circuits, a transmitting and a receiving circuit. Magnetic lines circulate round the closed core and, if they vary with the time, electrostatic lines encircle it in the manner shown on the right. The effects of these lines may be made evident by causing a number of conductors (in addition to the transmitting and receiving circuits) to encircle the iron core, whose circuits are completed through resistance, inductance, or capacity. If the air-gap between the two limbs A and B is sufficiently small an electromagnetic wave will be formed as shown in Fig. 18 in the case of resistance and capacity, whereby energy is conveyed from the transmitting to the receiving circuit. The wave of flux cuts the receiving circuit, inducing an electromotive force therein, and if [illegible] a current will also flow, of such magnitude that the resultant magnetomotive force summed round the entire circuit and including that required to overcome the reluctance of the iron is zero.

If these intermediate conductors be omitted and the air-gap between the two limbs be made large, our apparatus reduces to the ordinary transformer, which we may compare with an ordinary electric circuit, too short to permit of the development of a wave (see Fig. 19). In the electric circuit a difference of electric potential is set up by a generator of some sort between the limbs A and B, while in the transformer a difference of magnetic potential is set up by the primary or transmitting coil.

In the electric case (Case 1) this electric difference of potential appears almost unchanged at the terminals of the receiving circuit, being diminished only by the drop of pressure due to resistance in the line. In the transformer the magnetic difference of potential set up by the primary also appears almost unaltered at the extremities of the secondary, reduced only by the pressure drop due to reluctance in the iron. The electric potential difference of Case 1 is finally balanced by the potential difference across the receiving circuit, while in Case 2 the magnetic potential difference is balanced by that due to the secondary or receiving coil.

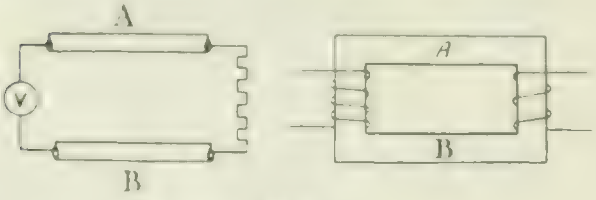


FIG. 19.

Just as any electric circuit has some self-induction, though this may be very small, owing to the fact that some magnetic lines interlink it, so any magnetic circuit has some capacity owing to the fact that some electrostatic lines interlink it. This is so small in an ordinary transformer that even its theoretical existence is [illegible] we [illegible] magnetic circuit by a conductor or conductors whose circuits are closed by condensers, say. The effect of this is analogous to surrounding an electric circuit with an iron core. In this case, in spite of the formation of a travelling wave, the whole of the energy entering the primary is received by the secondary.

If the conductors of Fig. 18 are closed through a resistance, however, a wave will still be formed (see Part 1), but it will be a wave of decreasing amplitude whose energy is gradually absorbed by the resistance of the conductor and transformed into heat, so that but little of the energy entering the primary coil can reach the secondary or receiving coil.

Such a wave satisfies the conditions laid down above as being necessary in order that mean force may exist on the conductors and that the force may always have the same direction. [illegible]

[illegible] will, therefore, [illegible] be a force on all the short-circuited secondary conductors urging them away from the primary: that is, the secondary will be repelled from the primary and the primary from the secondary. This statement may be interpreted to include the receiving coil among the secondary circuits if desired, or we may consider that practically the whole of the energy of the wave is absorbed before it reaches the receiving coil, which in this case may be neglected. This force is usually said to be due to the Elihu Thomson repulsion effect.

Let us consider the root-mean-square distribution of current and energy density or B^2 in such a transmission including the transmitting and receiving circuits.

The air-gap density on the outer side of the transmitting coil at C is zero as there is no reason why the lines of force should cross the air-gap in the manner shown dotted rather than pass wholly through iron as shown in the full lines. The same applies to the outer side of the receiving coil, also shown dotted. We may therefore conceive the function of the primary coil as being that of increasing the air-gap density from zero at C to O A at O (Fig. 20).

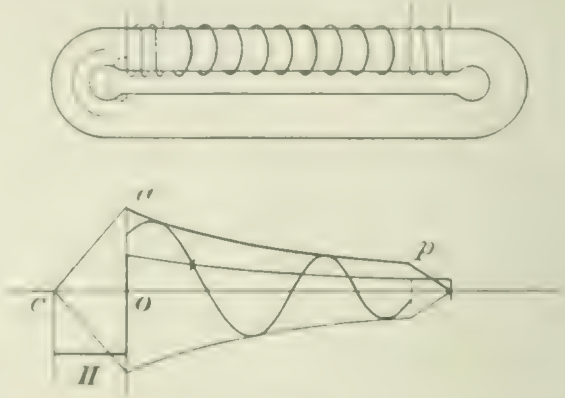


FIG. 20.

The primary current density (amperes per cm. length) which is constant is shown in curve H. When the density has reached the value O a at O due to the action of the primary coil, it begins to be reduced by the action of the short-circuited coils as we proceed from O to the right towards p. The current shown in curve H is now reversed, and instead of building up the density to still higher values begins to reduce it again. When we reach p the remainder of the density is absorbed by the receiving coil, on the further side of which it is again zero. By a fundamental law, as we have seen, $(1/\mu)(d\,B/d\,x) = \Delta$, the number of amperes per cm., and hence the current curve is the slope of the curve of densities and changes sign when this slope changes sign. This is clearly shown in the curve marked H.

If we compare two cases: (1) that in which there are a number of conductors arranged in slots and all carrying the same current, and (2) that in which there are a number of pairs of conductors in corresponding slots carrying equal and opposite currents (see Fig. 21), we see that in Case 1 the density continually becomes greater and greater, while in Case 2 the density is constant in all the teeth.

The function of the second set of conductors, therefore, may be said to be to restore the energy density or B^2 in those parts of the system where it has been weakened by the first set, and to weaken it where it has been increased beyond the average. For instance, in the figure the effect of the second set of conductors is to cause two lines to leave tooth 3 and traverse tooth 2, and two lines to leave tooth 4 and traverse tooth 3. Hence if one of these sets of conductors be primary and the other secondary conductors, we may say that the primary conductors continually restore the densities which would be reduced by the action of the secondary conductors.

In the case of the transmission previously discussed, however, the density is built up to its maximum value in one part of the system and reduced again by the action of the secondary in another part an essentially different arrangement.

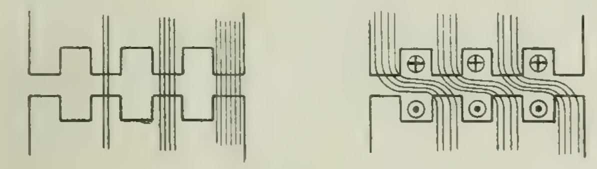


Fig. 21.

It is not necessary that the two limbs of our system should be made in one piece, but there may be an air-gap between them as in Fig. 22. In this case let the primary be held fixed and attached to the lower limb B, while the receiving coil is either fixed and attached to B or movable and attached to A and the short-circuited conductors *c, c, c* are attached to A. Then there will be a force on the limb A relative to the limb B, which will tend to move A in the direction of the arrow when B is fixed. If the motion produced by this force is to be continuous provision must be made for replacing the conductors *c, c, c* by others as they move away from the primary.

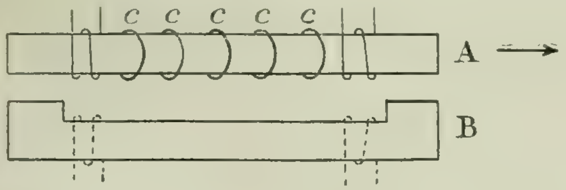


Fig. 22.

It is also unnecessary that the primary coil should surround the limb A, but it may surround the limb B instead as shown dotted in Fig. 22. All that is necessary now in order to get continuous rotation is that the limb A shall be made in annular form as in Fig. 23, where the transmitting and receiving windings are shown wound into large slots in a segmental stator which terminates at D. It is essential in this construction that it should terminate at D, as if it did not the primary would transmit waves equally in both directions and there would be no resultant torque.

Another method whereby the transmission of waves from the primary equally in both directions may be prevented is by placing the receiving coil so close to the primary that the wave is absorbed by it before it has decreased much in amplitude, the wave transmitted by the primary in the other direction travelling quite freely.

We may suppose that a multiplicity of such separate systems as shown dotted in Fig. 24 may be mounted so as to interact with a single rotor, or we may suppose that one system extends all round. In either case we have to remember that by proceeding sufficiently far round the core in a given direction we return again to the same point.

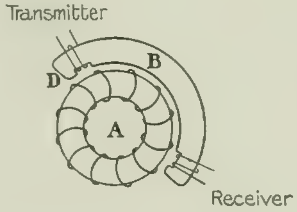


Fig. 23.

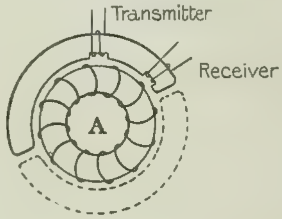


Fig. 24.

Bearing this carefully in mind we may regard our system as cut at A (Fig. 25) and developed into a flat surface A B H, in which case the two ends really represent the same point. In this figure the wave is propagated from the transmitting or primary coil in the direction of the arrow completely round the periphery until it reaches the receiving coil, where it is absorbed. Having been absorbed, either fresh energy is imparted to it by the transmitting coil and it again passes round the periphery, or a new wave is generated by the transmitting coil. Which of these two cases will occur depends entirely on the arrangement of the windings between T and R.

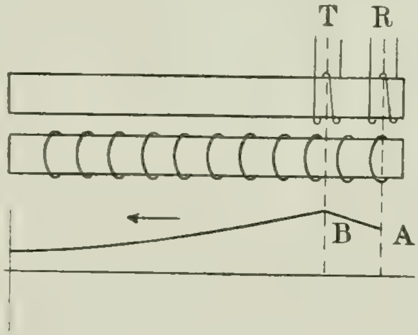


Fig. 25.

In whatever way they are arranged, however, their ultimate object is the absorption of a wave of small energy (the less the better) and the emission of a wave of much greater energy.

Before proceeding much further with the electrical case of our theorem it will be well to develop and apply thereto the well-known mechanical case of a vibratory cord.

A Mechanical Analogy to the Vibrations of the Electromagnetic System.

Before proceeding any further we shall explain more fully the well-known analogy between the vibrations of our electrical system and those of a cord, which we shall suppose to be submitted to a total tension P and of such length that the displacement y of the cord perpendicular to its length, i.e. to the X axis, is always very small relative to the total length. Now the tension of the cord is everywhere the same in amount and parallel to the tangent to the cord. It therefore varies in direction owing to the curvature of the cord when in vibration. Now the force tending to move any element of the cord is equal to the difference of tension on the two ends. These tensions as we have seen do not differ in absolute magnitude but only in direction, and for such small lengths of cord as we may assume to be circular arcs the difference of direction is proportional to the length of the element ds. Hence if dT be the difference of the tensions, we have

$$dT/ds = \text{force tending to move } ds.$$

This force is necessarily perpendicular to the cord, since the components of the tension on either end of the cord taken parallel to it are equal and opposite.

Now since the tension of the cord is constant in amount and varies in direction only, dT/ds is proportional to the curvature of the cord at the point considered.

On the assumption mentioned above that the displacement is small relative to the length and that the slope of the curve is therefore never very large, we may replace s measured along the curve by x measured along the axis, and thus obtain another expression for the curvature, viz. d^2y/dx^2.

We may now write $P(dy^2/dx^2) = F$, where P = initial tension on the cord, and F = force perpendicular to x. This force must be equated to the mass × acceleration of the element perpendicular to x. If the mass per unit length be m this gives $m(d^2y/dt^2) = P(d^2y/dx^2)$ as the equation of motion.

Let us now compare these equations and the quantities concerned therein with those of our electromagnetic system.

[illegible]	[illegible]
[illegible] flux at a point.	[illegible] = displacement.
[illegible] rate of change of [illegible]	[illegible] rate of change of y.
[illegible] force.	[illegible]
$d\Phi/dx = B$, magnetic density.	[illegible] $= y'$, slope of the curve.
[illegible] density.	[illegible]

[illegible]

[illegible] length.	[illegible] F, force perpendicular to x per unit length.
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

Thus there is a complete formal analogy between the two cases which we shall find very helpful as we go on. For instance, no abrupt change or discontinuity can take place in the flux Φ owing to the fact that magnetic lines are always closed, and similarly since we suppose our cord is continuous there can be no abrupt change in the displacement y.

We have seen that whether we consider the mechanical or the electromagnetic case, we arrive at the equation $d^2y/dx^2 = (1/v^2)(d^2y/dt^2)$.

The solution of this equation subject to the condition that when $x = c$, y is a pure sine function of t, is

$$y = A \sin(mx + pt) + B \sin(mx - pt).$$

A and B being arbitrary constants.

Two terminal conditions are necessary, and two only, completely to determine the constants A and B. These may conveniently be values of y at two different values of x. It follows, therefore, that a knowledge of the values of y for two given values of x completely determines y for all other values between the two given values.

In the case of the vibrating cord this is easily seen from the physical standpoint. If we know the motion of the two ends of the cords, the differential equation determines the motion of any intermediate point.

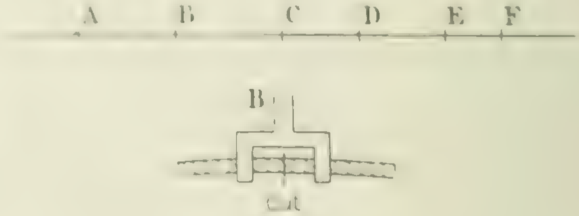


Fig. [illegible]

Similarly, if we know the flux entering the two ends of our apparatus we can tell how it is distributed at intermediate points.

If, however, we know the motion of more than two points of our cord we must divide it into a number of sections according to the number of points whose motion is known. For instance, if we have a cord whose motion is known at the points A, B, C, D, E, F, we must regard the sections A B, B C, C D, D E, and E F as separate cords vibrating independently (see Fig. 26).

If we suppose that at the point B the cord is clamped to some support which vibrates with a simple harmonic motion or otherwise, as in the figure, it clearly makes no difference, so long as the cord is clamped at the given point and submitted to a forced oscillation whether we cut it or not. If, therefore, we regard the motions of B and C, say as known and regard the cord as cut at these points, the motion of the remaining part of the cord causes no difference whatever to its motion between B and C. In fact we can remove the remainder altogether without affecting the part between B and C.

The above is the physical view of the fact which appears mathematically in the statement that two terminal conditions completely determine a particular solution of our equation.

The net result of the above discussion then is the following statement.

If at any two points, a cord (or electromagnetic system) is subjected to any forced motions whatever, the motion of the cord is completely determined between the two points and is absolutely independent of the motion of any other part of the cord.

Since in practice our electrical system will usually have its conductors disposed in a number of separate slots, it will be convenient in some cases to imitate this by considering a chain having a number of links of definite length instead of a flexible cord. The chain or cord is supposed to vibrate in a resisting medium producing a decrement.

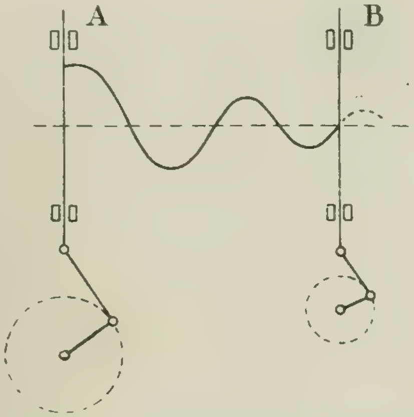


Fig. 27.

The analogue of our electrical system is then the following.

The cord or chain is supposed to vibrate between two sliders whereby the ends are held and a certain tension imparted. No matter how great this tension the sliders are supposed to be without friction or mass, unless otherwise stated. If the slider at one end is set in simple harmonic vibration, say by a crank and connecting rod mechanism as in Fig. 27, while the motion of the cord is damped by friction, a decreasing wave will travel from the end in forced motion to the other end.

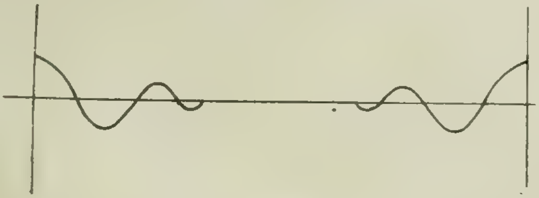


Fig. 28.

In the general case both ends may be in forced motion, and in this case the left-hand oscillator produces a wave flowing to the right and the right-hand oscillator a wave flowing to the left.

This is readily seen in cases where the damping is so great that each wave dies away before the other commences (Fig. 28), but even if this is not so the two waves will exist superimposed on one another. The amplitudes of the two waves will be such that the sum of their amplitudes at the two ends is equal to the known amplitude of the forced oscillation at every instant.

Suppose, for instance, that the left-hand oscillator A (Fig. 27) produces a wave travelling to the right, and that the cord does not terminate at B but extends as shown dotted to an unlimited distance. Then the slider B will be set in oscillation in a certain definite manner, depending on the amplitude and frequency of A's oscillation and the mass of the cord together with the amount of damping.

Suppose now the slider B to be kept in a forced state of motion, by means of crank mechanism or the like, which is exactly the same in frequency, amplitude, and phase as that which it had before when it was free, while that portion of the cord shown dotted on the right is removed. The motion of the cord between A and B will be absolutely unchanged, the crank mechanism now supplying the force previously supplied by the reaction of the part of the cord shown dotted on the right.

Under these circumstances the wave generated by the oscillator A is said to be completely absorbed at B. Complete absorption can only take place for a single particular amplitude and phase of the oscillation at B, viz. that determined by the wave motion due to A. If the motion of B differs from this a second wave as mentioned above will start from B travelling towards the left and having an amplitude at B at every instant equal to the difference between that of the wave determined by A at B and the forced amplitude of B. This differential wave is usually spoken of as a "reflected wave" when regarded with reference to A, while the wave travelling towards B and away from A is called the "incident wave."

Two particular cases of reflected waves are of special interest:—

(1) The case in which B is permanently fixed and its amplitude is zero. The wave due to A is then said to be completely reflected at B. In this case the forced amplitude of B is zero and the magnitude of the reflected wave according to the above rule is equal to the difference between zero and that of the wave determined by A. In other words the incident and reflected waves are equal and opposite at B, their resultant being therefore zero.

(2) The case in which the slider at B is quite free, the cord being supposed to terminate there. This must be carefully distinguished from the case discussed above where the slider was quite free but the cord (shown dotted in Fig. 27) was supposed to extend to infinity. As mentioned above, the forces due to the reaction of the right-hand or dotted section of the cord serve to modify the motion of the cord between A and B, which is therefore different from that of a cord terminating at B, at which point therefore the force acting on it is zero.

We saw above that the force on our elastic cord was proportional to its curvature, and it is easy to see that the curvature of an elastic cord naturally straight will be zero at a free end, but not zero at all times at an intermediate point of an indefinitely long cord.

The following considerations will help us very much to obtain clear ideas of the motion of a cord having a free end :—

The waves we have hitherto been discussing have been waves of displacement from a mean position which the cord would have if there were no motion. Since the force acting on the cord at any point is proportional to the curvature of the cord, such waves of displacement must be accompanied by waves of force of the same general vary the [illegible] in magnitude and phase. Such a curve of force distribution is plotted in Fig. 29 and has a fixed phase relation to the wave of displacement so that it moves at the same speed.

Instead of considering waves of displacement, therefore, and deducing therefrom the values of the force at any point, we may consider waves of force directly and deduce therefrom the displacement at any point. If we do this the present case in which the slider B is free is reduced to the former one, since the force at B is now zero, whereas before the displacement was zero. Hence everything said about Case 1 applies to Case 2 if we interchange the two words "displacement" and "force." In other words we may state the following theorem :—

The two cases of a cord carrying wave motion and fixed at one end and that of a cord carrying wave motion and free at one end are reciprocal to one another, the force in the second case corresponding to the displacement in the first.

Hence, if the end of the cord is free at B, and the force, therefore, zero we can decompose the force wave into incident and reflected waves which are equal and opposite at B, their resultant being zero. Thus in Case 1 the displacement is completely reflected at B, and in Case 2 the force is completely reflected. Similarly, if the force used [illegible] at B be equal to that excited by the incident wave due to A and B, we have a case where the force wave is completely absorbed.

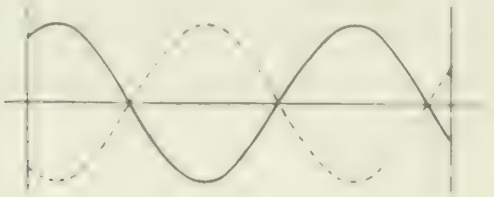


FIG. 29.

Since, as we saw above, force corresponds to current and velocity to electromotive force in the case of our transmission, or conversely force to electromotive force and current to velocity in the cable, we may compare the cord having a free end with a cable having its end earthed where the electromotive force is zero but the current free, while the cord with the fixed end we may compare with the cable whose end is insulated so that the current (velocity in the mechanical case) is zero but the electromotive force free.

We have now carried the mechanical case of our general physical theorem to a point where we may usefully employ it further to elucidate the electromagnetic case.

We may compare the primary or transmitting coil to the oscillator A and the receiving coil to the oscillator B which absorbs wholly or partially the oscillations transmitted from A. If work is done by A on the cord in setting up the oscillations, an amount of work may be given out by B equal to that put in, less the work done by the cord on the resisting medium. If the work done by the cord is equal to the amount put in at A, then the wave dies away before it can reach B and B can do no work. Exactly the same remarks apply to the electrical case.

We saw that it was necessary to consider the flux at the two ends of our transmission to be the same on account of its annular nature. To parallel this we must consider the displacement of the two ends of our cord to be the same, the fact that all magnetic lines are necessarily closed being paralleled by considering that our cord is unbroken and forms a loop.

Let us now parallel Fig. 25 by Fig. 30, showing the exact relation between the cord and the electromagnetic case. The transmitting coil or primary is now compared with A, a slider which is vibrated with a large amplitude,

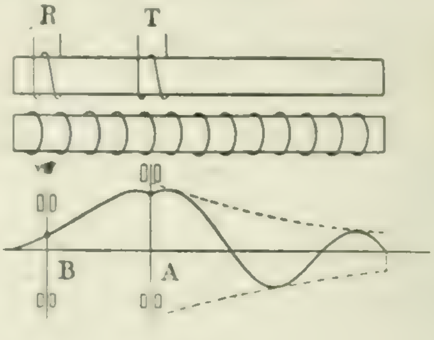


FIG. 30.

generating a wave which travels to the right around the loop and reappears on the left of B. It is there absorbed by B, an oscillator vibrating with small amplitude, and passes on to A again to be re-transmitted round the loop. The distribution of energy density in both cases is exactly the same, the object of the two oscillators being, as before, the absorption of a wave of small energy and the emission of a wave of much greater energy.

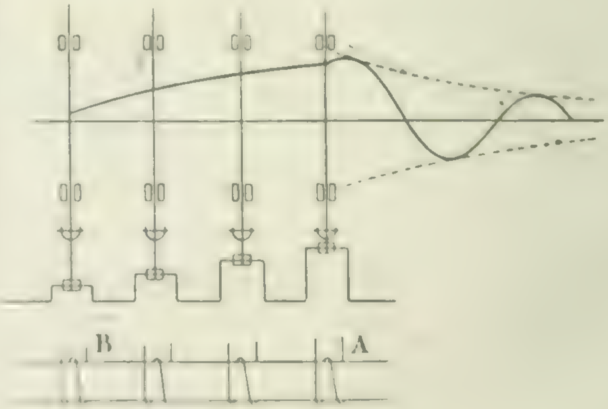


FIG. 31.

In both the above diagrams we have shown the two oscillators as being each concentrated at a single point of the system, the motion of the wave being of the same general type (i.e. consisting of an incident and a reflected wave) in both the two intervals between A and B. If, however, B is adjusted to absorb the wave travelling from A towards the right, it cannot absorb that travelling towards the left as well, and hence this wave will be largely reflected.

Another arrangement which we may adopt in our cord and which has useful electromagnetic analogies is the following :—

Between A and B we have a number of intermediate oscillators of varying amplitude and phase, typified by the multi-crank mechanism of Fig. 31, which serve to guide the cord and fix its oscillation at every point between B and A. This converts the wave between B and A into a forced wave, while it still remains free in the other interval between A and B.

In this case it is perhaps better to think of the cord as a chain fixed to the sliders at the junction between two rigid links.

In the electric case we think of the member carrying the transmitting and receiving coils as being slotted and carrying a number of intermediate coils excited by electromotive forces of differing amplitude and phase—carrying in fact an unbalanced or elliptical polyphase winding.

It is clear in the case of the cord that A and B must not be placed too close together owing to their different amplitudes of movement, or there will not be sufficient cord to allow them to execute their vibrations independently.

Similarly in the magnetic case we must not put A and B too close together or the density between them (slope of the cord) will become too great. Subject to these conditions, however, they should be placed as close together as possible.

ROTATION.

We have now to consider what occurs when the apparatus is in motion. As the result of the investigations given in Part I we find that when the secondary is in motion relatively to the primary the wave is carried along in the direction of motion. Thus if the motion of the wave is in the direction of motion of the secondary its decrement is reduced by the motion, since when the secondary is in motion the wave is carried a greater distance while decreasing by a given amount. If the direction of the wave is opposed to that of the motion, its decrement is increased since the wave cannot travel so far while decreasing by a given amount. The decrement in fact is proportional to the slip between the motion of the wave and that of the rotor.

We also find that in the absence of condensers or commutators, i.e. of means for self-excitation, the motion tends to smooth out the ripples in the wave, i.e. to increase its wave-length, and this to an equal degree whether travelling with or against the motion.

Fig. 10 in Part I summarizes the characteristics of the wave motion in a similar manner to the circle diagram that is in such common use for polyphase induction motors.

It will be remembered that the equation of this curve is

$$S^2 = a^2 + m^2 = (p\,\mu/r_2)\cot\theta = (p\,\mu/r_2)(a/m),$$

if the flux wave be represented by

$$\Phi = \Phi_0\,\varepsilon^{(a+jm)x+jpt}, \text{ giving } B = (a + j\,m)\,\Phi.$$

We saw above that the primary ampere-turns are equal to the sum of all those in the closed secondary circuits, supposed to extend to infinity in one direction only, say to the right, from the primary at $x = 0$. We shall not at first take account of conductors on the left of the primary, but, having dealt with those on the right in the first place, shall find no difficulty in taking account of the others later on.

Since $\Delta = (1/\mu)(d\,B/d\,x)$,

$$\text{total secondary ampere-turns} = \int_0^\infty \Delta\,d\,x = \frac{1}{\mu}\int_0^\infty \frac{d\,B}{d\,x}\,d\,x$$

= the value of B when $x = 0$, since B is zero at infinity.

Hence the value of B at the origin is proportional to the current in the primary coil and may be taken to represent it both in magnitude and phase. We have just seen that $B = (a + j\,m)\,\Phi$ and $E = j\,p\,\Phi$. Hence, if we lay out Φ_0, the flux threading the primary coil, as a horizontal vector in the above diagram, E will be represented by a vertical vector and O P or $a + j\,m$ will represent the current in the primary coil.

This diagram not only informs us as to the values of a and m at different speeds, but it also gives the current and power factor in the primary coil. It is in fact a complete epitome of the wave motion at all speeds.

It will be remembered that we arrived at the following constructions of the principal quantities involved :—

If O P is a vector to the curve $S^2 = (p\,\mu/r_2)\cot\theta$ and S P_1 is the hyperbola $x\,y = p\,\mu/(2\,r_2)$ intersecting it in S. Then Y P_1 is the speed of the wave ; P P_1 is the speed of the rotor to the same scale ; Y P $= a$ is the rate of decrement and also the slip of the rotor relatively to the wave ; O P is the primary current ; O Y $= m$ is proportional to the number of poles per unit length ; U T is the torque due to the wave.

It should be mentioned that the speed v is taken positive when in the side we are considering the rotor is moving away from the primary coil, and negative if it moves towards it. The wave always flows away from the coil.

By way of an example we may elucidate the application of such a diagram by considering how with its aid we may calculate the wave motion due to a single ring-wound primary co-operating with a short-circuited secondary and wound on a core of such diameter and constants that the wave motions in both directions die away before they interfere with one another.

First of all from the dimensions of the apparatus, the cross-section of bars, core length, and air-gap we calculate the two constants r_2 and μ, and thence $p\,\mu/r_2$. These known we proceed to plot the two curves mentioned above. We have next to determine the scale to which Y P_1 represents the synchronous speed of the wave $v_0 = -p/m$. Since O Y $= m$, we can readily calculate v_0 for any value of O P and the corresponding length of Y P_1 and so determine the scale.

If we suppose the rotor (Fig. 5) to revolve in a clockwise direction, then on the right of the primary it will be moving away from it and on the left towards it. Hence O P corresponding to v positive, or moving with the wave, is correct for the disturbance on the right, and O P_2 (v negative) for that on the left. The first thing which we notice is that the ordinate m determining the speed of the wave is the same in both cases, and hence that the wave flows away from the primary coil at the same speed in both directions. But the decrements vary very much, being, as stated above, proportional to the slip between the wave and the rotor, and therefore being very great when is negative and very small when it is positive. The vector O P, as has also been mentioned above, represents the total current required in the primary to supply the rotor section on the right-hand side of it from the primary and similarly, while O P₁ represents the current required for the section on the left-hand side. The total current in the primary is therefore proportional to the vector sum $O\,P + O\,P_2 = 2\,O\,P_1$, and therefore to another scale the hyperbola $x\,y = p\,\mu/(2\,r_0)$ is the locus of the primary current as we vary the speed.

It has also been shown (Fig. 10) that the torque due to such a wave motion is proportional to the intercept between the point U and the point T where O P (or O P produced) cuts a horizontal line U S. In the case which we are studying, the resultant torque will be the difference between the "motor" torque U T due to the wave which flows in the same direction as the rotor and the much larger back torque U T′, where T′ is the point where O P produced cuts U S, due to the wave flowing in the opposite direction. The resultant torque is always opposed to the direction of motion and the apparatus is a brake absorbing large lagging currents in the primary, the $R\,I^2$ losses being supplied by generator action within the machine.

In Part 1 the effect of various modifications of the constants of the apparatus on the diagram are fully investigated, such as the effect of including inductance or capacity in the rotor circuits or of winding the stator with auxiliary coils in addition to the exciting coil, closed through inductance or capacity. However, as the case we have discussed is the most important one it is unnecessary to recapitulate the others.

Having discussed fully the effect of a single ring-wound exciting coil on a short-circuited rotor we can readily proceed to consider two such coils spaced a certain distance apart and carrying equal and opposite currents. These two coils are equivalent to a single drum-wound coil. Having discussed one drum-wound coil we can then proceed by the method of super-position to build up the effects of a number of drum-wound coils, thus arriving finally at the exact occurrences which take place in a slotted stator of the ordinary type when used with a squirrel-cage rotor. These will often be found to differ quite widely from those which would be expected from the ordinary sine-wave theory. Such an investigation, however, must be reserved for a separate paper as it is far too long to be given here.

We may again illustrate these facts by reference to a vibrating cord. As one of the most important points we have to study is the results they lead to when limited by certain terminal conditions, we shall first suppose our cord to be fixed at both ends.

The question we have to discuss is: What will be the wave-shapes of the system if the decrement is so small that very little of the wave energy is absorbed before it reaches the reflector, subject to the condition that the decrement of the reflected wave is much greater than that of the incident wave, while their wave lengths are the same?

If the oscillations are so slow that the eye can follow them, or if they are observed by stroboscopic means, we shall see a wave starting from the oscillator at a definite rate of travel towards the right. As it proceeds the rate gets slower owing to the effect of the reflected wave, and finally when it reaches the reflector it becomes stationary (see Fig. 32). On the left the reflector or fixed point may be placed so closed to the oscillator that the standing portion of the wave extends practically up to the oscillator, or better still we have a forced wave between reflector and oscillator, whereupon we get practically the condition shown in Fig. 32.

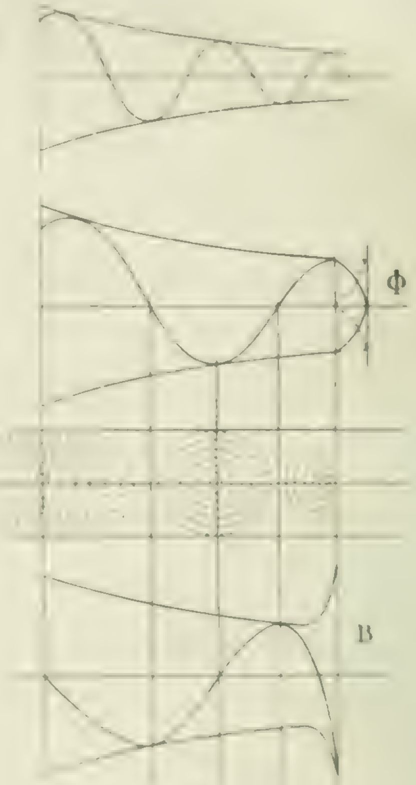


Fig. 32

In Fig. 32 is shown an electromagnetic case of such a system in which the incident wave has a small decrement and the reflected wave a very great one. This, as we have stated, is characteristic of the case where there is relative motion between the primary with its reflector and the secondary.

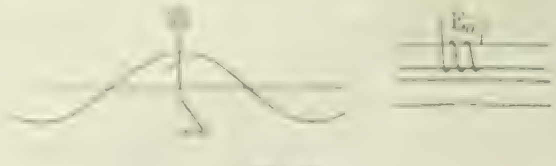


Fig. 33

We see that in this case the wave proceeds much as before till it reaches the immediate neighbourhood of the reflector, beyond which it cannot pass, and since all the lines of force must be closed they are crushed into a very small space adjacent to the reflector giving rise to very high densities indeed at that point. In practice saturation would somewhat relieve these densities.

Flux and density curves are shown above and below, in the upper curve the small decrement of the incident wave and the great decrement of the reflected wave (shown dotted) being clearly seen. The resultant wave is the sum of these at any point.

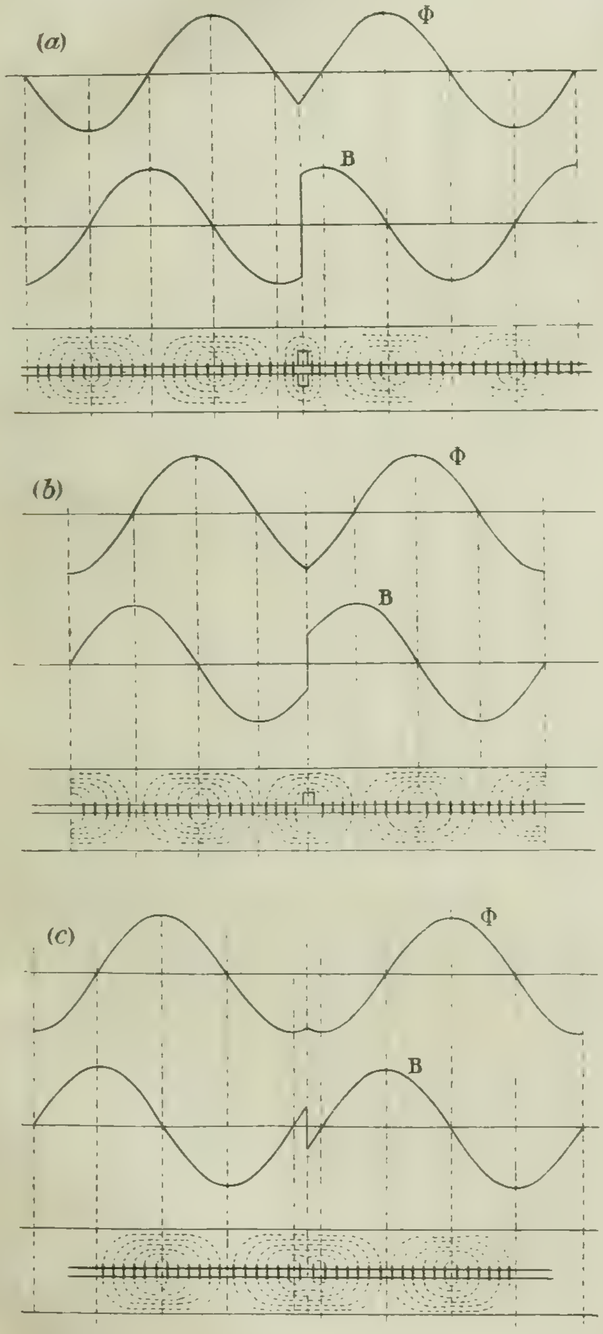


FIG. 34.

It is easily seen by the aid of the general physical theorem with which we started that an increase of density in the direction of motion gives rise to a retarding torque, which in a motor should be avoided.

We shall now endeavour to get a clear physical idea of the method of generation of wave systems both in the electric and the mechanical case. We shall take the case of a cord or iron core of indefinite length, oscillated at one point. In the mechanical case we may suppose the cord gripped at one point and a simple harmonic oscillation impressed on it by a crank and connecting rod mechanism as shown. In the electromagnetic case a concentrated exciting coil is supposed wound round one point of the core and this is excited by a simple harmonic electromotive force (see Fig. 33).

In Fig. 34 are shown diagrams of five phases, illustrating the generation of two travelling waves, mirror images of one another, by this method of setting up oscillations, whether in the electric or mechanical case.

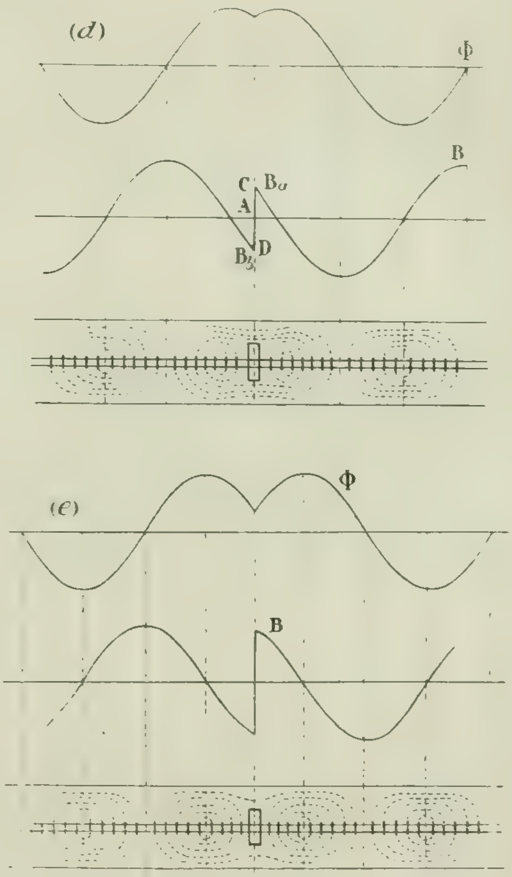


FIG. 34—*continued*.

The upper curve shows flux Φ or displacement y, the second magnetic density B or slope y', and the lower diagram shows the distribution of lines of force corresponding to the flux and density above them.

We see that at the origin or point of oscillation there is a cusp in the Φ curve, though Φ does not change in value, since all magnetic lines are closed, and an abrupt break in the B curve where B changes abruptly from positive to negative. Let us confine ourselves to the electromagnetic [illegible] the moment. We saw in Section 2 that [illegible] $= \Delta$ the current density and therefore

$$\int \Delta \, dx = \frac{1}{\mu}\int \frac{dE}{dx}\,dx = \frac{1}{\mu}(E_1 - E_2)$$

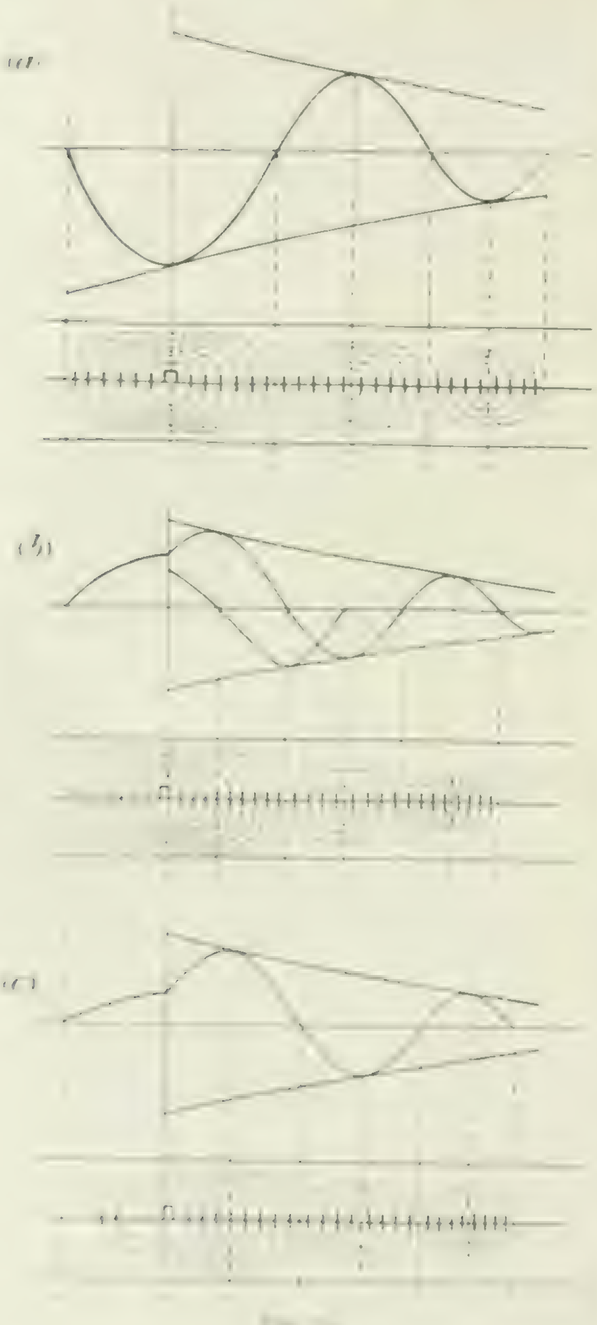


Fig. 34.

[illegible] total current between $x = a$ and $x = b$. In general as a and b approach one another E_a approaches E_b and thus the total current goes to zero here.

Now let us take a and b on opposite sides of the discontinuity of Fig. 33. As a and b approach one another $E_a - E_b$ no longer approaches zero but tends to assume a value equal to the total length C D of the break. Hence we conclude that

Total current at the point of discontinuity $= (1/\mu)$ C D or

The discontinuity in the curve of densities measures the current in the exciting coil.

In the mechanical case we find —

The discontinuity in the curve of slopes measures the force supplied by the oscillator.

As we saw above at points of discontinuity such as A we may suppose that one section of the cord terminates and another begins. In that case A C is the force necessary to balance the reaction of the rope on the right of A, and A D that necessary to balance the reaction on the left of A. In the electric case A C is the current necessary to excite the disturbance on the right and A D that necessary to excite it on the left.

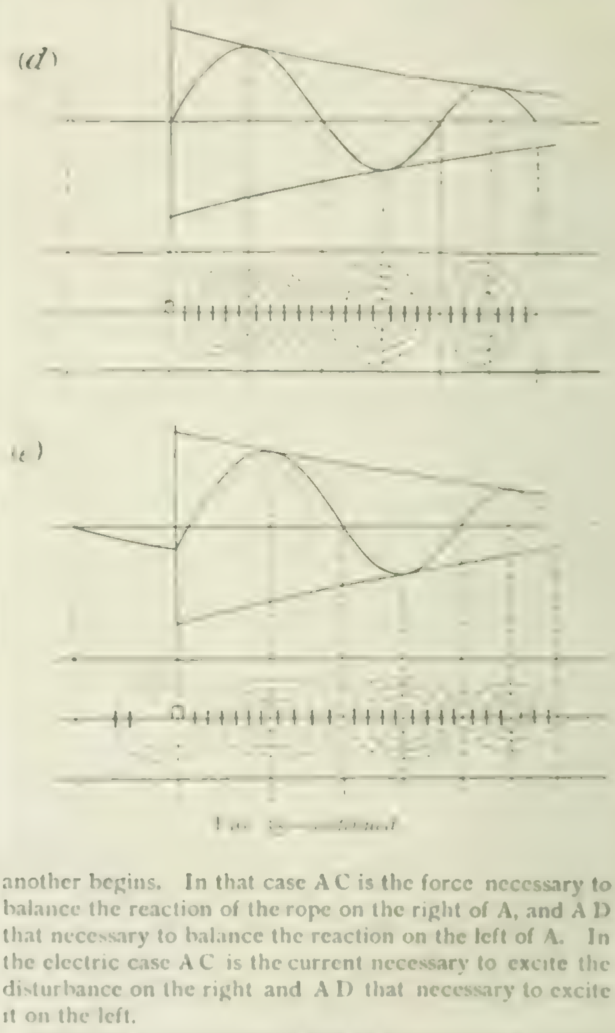


Fig. 34—continued.

Returning to the curves of Fig. 34 we may note a number of interesting points:—

(1) Starting with Fig. 34 (a) we see the lines of force which form the curve start with a small nucleus surrounding the exciting coil.

In Fig. 34 (b) the nucleus has grown almost to its full proportions, while in Fig. 34 (c) the single nucleus we have hitherto been dealing with begins to become double, some of the lines of force on either side forming a closed circuit which does not enclose the exciting coil. In Fig. 34 (d) this action has proceeded much further, while in Fig. 34 (e) our original nucleus has almost divided into two entirely distinct waves. Coming back to Fig. 34 (*a*) again a fresh nucleus starts which is now of opposite sign, there being two to each complete period, one positive and one negative.

(2) It is instructive to see that when the flux interlinking the exciting coil is greatest in Fig. 34 (*c*) the primary current C D is least. This current is in quadrature with the flux, and therefore in phase with the electromotive force.

(3) It is also very instructive to note how the direction of the lines of force reverses when the flux curve crosses the zero line, so that the portion of the flux curve between two crossings of the zero line forms an isolated portion or nucleus of the wave.

Let us now study a case of a wave motion reflected at a point. A point of reflection is a point such that the displacement which is represented by a wave is necessarily zero at the point. If we have a travelling wave going towards a point it will be reflected at the point and another travelling wave superposed on it of such magnitude that the two are at all instances equal and opposite at the point of reflection. The resultant vibration of the cord is a standing wave having its node at the point of reflection, and extending from the point of reflection where the displacement or flux is zero to the point of oscillation but not beyond.

In the case of a vibratory cord a point of reflection is formed at any point of the cord which is clamped so as to be incapable of movement, y being necessarily zero at all times.

In the electromagnetic case a point of reflection is formed by a short-circuited coil surrounding the iron core or by a termination thereof.

In Fig. 35 are shown five stages in the generation of a wave train by an oscillator fitted with a reflector. For the sake of variety we have shown the generation of a wave with logarithmic decrement in this case.

Starting, for instance, with Fig. 35 (*a*) we see the flux at its maximum surrounding the exciting coil.

In Fig. 35 (*b*) we see that the wave has begun to travel towards the right and some of the lines of force which before surrounded the exciting coil are now able to close without doing so. In the portion of the core between the reflector and the oscillator, however, the density is simply reduced without any change in distribution.

In Fig. 35 (*c*) we see that this action has gone further, the greater part of the lines now closing without surrounding the exciting coil.

In Fig. 35 (*d*) the whole of the flux is on one side of the exciting coil, there being none whatever between oscillator and reflector. While in Fig. 35 (*e*) we see how the nucleus of a new wave grows up surrounding the exciting coil again, and when it has grown to its full dimensions in Fig. 35 (*a*) again, it commences to move off to the right, the lines of force of which it is composed cutting the exciting coil as they do so.

Another important point to note in the case of a wave with decrement is that its maximum which is the point where the density is zero is now no longer midway between the two points at which it crosses the zero line.

The effect of this is to make the density on the rear side of the nuclei of which the wave consists greater than that at the front, and this generates a drag on the conductors in the direction of motion of the wave. The power corresponding to the product of this force and the speed of the wave, is stored up as magnetic energy in the wave and supplied by the decrease of the flux as it proceeds.

We have hitherto considered wave trains proceeding from an oscillator whose oscillations were of constant amplitude, or in the electric case we have considered cases where a constant flux or electromotive force was applied to the oscillator, and from this assumption we have determined the force (or current).

We shall now consider the case where the force (or current) is regarded as fixed and endeavour to determine the amplitude (or flux in the electric case).

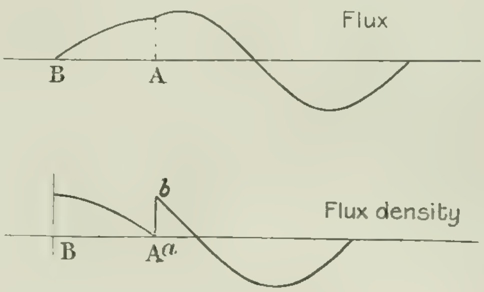


FIG. 36.

Let us first take the case of an oscillator at A and a reflector at B a quarter wave-length away from A, and compare it with the case in which no reflector exists. The effect of the reflector as we saw above was to reduce the wave train between A and B to a stationary wave having its node at B. If we draw curves showing the flux density we note that the flux density at A due to the standing wave is always zero (see Fig. 36). If now we draw corresponding curves for the case where there is no reflector, we see that the density at A due to the wave train on the left is no longer zero but equal and opposite to that due to the wave train on the right (see Fig. 37). Now on the hypothesis of constant current the distance $a\,b$, in the two figures must be equal and hence the amplitude of the right-hand wave train must be twice as great where there is a reflector as where there is none.

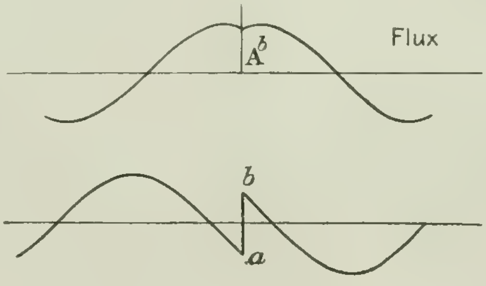


FIG. 37.

Thus a given force applied to the oscillator (or current flowing in the primary coil) gives rise to a wave of displacement (flux) having twice the amplitude in the case of a reflected wave of that obtained when we have two wave trains, mirror images of one another. In other words it takes twice as much power to generate two wave trains as it does to generate one of the same amplitude.

[illegible] n, thereby doubling its [illegible] what occurs in other portions of the cord. In other words the different sections into which the system is divided by the oscillator and reflector are no longer independent of one another.

In fact, the above instance is only a particular case of an important general theorem.

[illegible] effects being merely superposed.

It is this theorem that permits us to build up the flux distribution in a slotted stator from a knowledge of that due to one drum-wound coil.

DISCUSSION ON "WAYLEAVES."*

BEFORE THE INSTITUTION

Mr. F. GILL (*communicated*): Possibly the body most largely affected by the wayleave problem was the National Telephone Company, and it may be of some use to those now concerned with this problem to set out briefly some of the facts in the case of that company. From the nature of the case the telephone lines fell into two groups: (1) those in which large masses of wires required underground facilities in towns; and (2) those in which few wires were required overground to scattered subscribers. Those in the first group had urgent need of wayleaves, while those in the second group could not stand a heavy rental to numerous wayleave grantors. The sums paid for wayleave facilities had, of course, ultimately to be paid by the subscriber, and these amounted to £167,000 per annum, equal to over 7 shillings per annum from each telephone station, nearly 6 per cent of the total rental. Prior to 1892 the Post Office charged the telephone companies a rental of 20 shillings per annum per mile of wire for permission to carry wires over and along railways and canals on which the department had acquired exclusive right of way, the companies having to satisfy the owners also. The company possessed no facilities in virtue of Provisional Order or Act of Parliament, except as mentioned later. On several occasions it pro- [illegible] ized the Postmaster-General to transfer his wayleave powers to the company upon two conditions: (a) A licensee was not to exercise any powers under the said enactments except in an urban sanitary district or [illegible] was not to exercise [illegible] without the consent [illegible] district outside London of the urban sanitary authority, and elsewhere of the county council, and was to be subject to any terms and conditions which the county council or urban sanitary authority might attach to any such consent, and was to comply with any such regulations of such council or authority from time to time in force in relation to telegraphic lines. The local authorities proceeded to fasten upon the idea of being able to dictate terms, and in most cases extracted a rental for underground facilities, a fairly common one being 5 shillings per subscriber per annum. In the most flagrant case, however, London, the situation was much worse and the London County Council after passing a series of resolutions setting out the terms of their consent to the company, 12 months afterwards went back on the bargain and sought to fix the rates the company was to charge its subscribers and to impose a very heavy penalty for the wayleave.* There appears to be every reason to believe that the Post Office will continue to regard all roads, railways, and canals as its own special field, and oppose the granting of powers which seem likely in any way to limit its scope. In any legislation it is specially desirable that terms should be fixed by Parliament so that local authorities may not have the power to impose unreasonable conditions in return for grant of wayleave facilities. Mr Gill.

Mr. A. P. [illegible] question about the justice of an appeal to the Board of Trade or to some other competent authority against the veto by the local authority. The South Wales Electric Power Act 1904 provides that "The consent of the local authority shall not be unreasonably withheld, and if any question arises whether that consent is unreasonably withheld or not, that question shall be decided by the Board of Trade." This, of course, should apply all over the country. But the adjustment of wayleaves is a much more

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* [illegible]

* [illegible]

. Trotter. difficult matter, and it does not appear to me (and I write only for myself) that the Board of Trade could undertake it satisfactorily through the administration of the Harbour Department. Fortunately there is an already constituted body with wide experience in very similar work, namely, the Light Railway Commissioners. They are in the habit of examining districts, hearing evidence on the spot, considering the merits of cases and of the industrial importance of communications, settling of purchase money, and compensation for taking land. Some of the most scandalous cases of extortionate wayleaves consist in blocking only a mile or less of a route, and the usual procedure for considering and facilitating the construction of a light railway could not be set in action for each case separately. But groups of test cases could be submitted, and powers should be given to the Commissioners to revise any compensations which had been agreed since the date of their acquisition of these powers. With slight alterations Sections 7, 21, and 22 of the Light Railways Act 1896 are readily applicable to wayleaves for overhead wires and for underground cables. The examples quoted in the course of the discussion before the Institution of the price paid per acre are not to the point. The inconvenience to a householder of a pole planted in the footway immediately opposite his front door is not to be estimated by the sectional area of the obstacle. Poles on arable land interfere with ploughing and harvesting, and they can be reduced in number by using long spans. On the other hand, it may be observed that an upstanding rock is found planted near the middle of most of the fields in some parts of Cornwall. Whatever their original purpose, farmers do not seem to think it worth while to remove such rocks.

r. Vernier. Mr. C. VERNIER (*in reply*): I regret that Mr. Chamen's valuable communication (page 351) which gives the proposals of the Joint Committee of the Incorporated Association of Electric Power Companies and the Incorporated Municipal Electrical Association, only reached me after I had completed my reply (page 355) in the May number of the *Journal*. The importance of these proposals merits special consideration in that they are the considered conclusions of a Committee whose competence is indubitable. I think it is only right, however, that I should call attention to some of the limitations of these proposals, limitations which I am confident the Committee themselves would be the first to acknowledge, and which I think must be attributed in the words of Mr. Chamen to "such powers as it is reasonable to expect that Parliament will give"; to which I would add "under a private Bill." Briefly these proposals may be summarized as follows:—

(1) The undertakers may apply to the Board of Trade for a certificate of the public utility of a main.

(2) On receipt of such an application the Board of Trade will notify the landowners and invite them to forward their observations within one month.

(3) The Board of Trade may thereafter decide to issue or withhold a certificate of public utility, either with or without a local inquiry.

(4) The amount of the compensation and all other questions arising in respect of the lines, unless mutually agreed between the parties, shall be fixed by a single arbitrator appointed by the Board of Trade. This same arbitrator shall sit continuously.

Mr. Vernier. The first three of these proposals are closely in agreement with the views which I have given in the paper and in my reply to the discussion. The fourth is also on the lines of one of my proposals put forward for discussion under par. *b* (1).* In this case, however, I made certain stipulations adopted from recent Acts, such as the Housing and Town Planning Act, 1909, designed to reduce the costs of arbitrations. Unless the cost of arbitration is minimized, the powers contained in the Committee's clause can seldom or never be exercised to limit exorbitant rents, but will only be useful in the most obstinate cases of a complete refusal to allow the grant of a wayleave. An ordinary Board of Trade arbitration is by no means an inexpensive method of settling disputes, and taking into account the costs of the arbitration and legal expenses in connection therewith, will seldom be less than £50 and may easily run into three figures.† To this must possibly be added the cost of a Board of Trade inquiry before a certificate of public utility is granted, which would have to be borne by the undertakers. As I mentioned in my reply (page 360), on account of the numerous landowners commonly encountered on a route the amount of wayleave rent involved in any particular case is often under £10 and seldom exceeds £20 per annum, which means that recourse to arbitration will usually absorb the utmost possible saving on rentals for many years. This would not perhaps be serious if awards in such arbitrations were accepted as a precedent in the fixing of rents by other landowners, which is not in the least likely, for although precedents usually receive consideration at the hands of local authorities and other corporate bodies who value their prestige, this seldom applies to individuals. It is, however, really only in this way, and also through the moral effect of a Board of Trade certificate of the "public utility" of the proposed main, that undertakers could expect any relief from exorbitant rent charges under the proposed Bill.

I would here make the suggestion that if arbitration is the method adopted, all landowners, tenants, and occupiers on the route of a main declared by the Board of Trade to be of public utility and desirous of having the question of compensation determined by arbitration should be convened at one and the same hearing of the arbitration in order to reduce expenses. I assume, of course, that the arbitrator would have in his discretion the awarding of the expenses of the arbitration.‡ This is very important, as unless the arbitrator can exercise discretion in the award of costs, landowners who wished to secure exorbitant rents might refuse to quote reasonable terms so as to compel the undertakers to go to arbitration, knowing full well that the terms they demand are not less good than the terms the undertaker would be likely to secure in an arbitration, plus the expenses and trouble of the arbitration. Further, it is suggested that the same Board of Trade arbitrator sitting continuously shall hear and determine "all" questions arising in respect of the line or lines authorized by any certificate of the Board of Trade.

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* *Ante*, page 336.

† In two cases of Board of Trade arbitrations within my experience, which were of the simplest character, not occupying the arbitrator's attention for more than one hour, the total costs amounted to close upon £50.

‡ Electric Lighting Act 1882. Section 28.

[illegible]

[illegible] produce a certificate of its public utility, and yet other [illegible] elect to have the terms settled by arbitration [illegible] not sufficient. therefore, to rely upon the mora [illegible]

[illegible] e that the electrical industry will eve [illegible] will remove present obstacles and difficulties. The prospect opened up by the recent appointment of the Board of Trade Electric Power Supply Committee offers an opportunity for a much bolder policy, which should be pressed unflinchingly. As, moreover, the electrical industry cannot reasonably expect to secure greater facilities from Parliament than it considers essential to its best and freest development, our claims to this Committee should not be vitiated by any thoughts of pre-War prejudices or fettered by any such considerations as hampering precedents. I am here referring not merely to the question of compulsory wayleaves, but also to the larger questions referred to this Committee, with which the subject of this discussion is so intimately bound up.[*]

I think it would be well if I recapitulate the several points which I would consider essential to a really useful practical scheme for compulsory wayleaves.

- (*a*) That a certificate of the public utility of a proposed main be granted, or alternatively an Order for the compulsory acquisition of easements be issued by the Board of Trade on the application of statutory undertakers in suitable cases.
- (*b*) The total time allowed from the date of application to the issuing of a certificate or of an Order, or its refusal, not to exceed 3 months.
- (*c*) Compulsory powers to be allowed for entry upon the land in urgent cases before the determination of the compensation.
- (*d*) The method adopted for the fixing of compensation in case of dispute to be in the first instance of the cheapest and most readily accessible description supplemented by a right of appeal to some judicial body. The determination of all technical questions to be in the hands of the Board of Trade.
- (*e*) The terms of tenure to be in perpetuity (or for at least 50 years) subject to the landowner's right to the reasonable use and development of his land, and for this purpose to require the removal or diversion of a main on giving sufficient notice at the cost of the undertakers. A right of appeal to the Board of Trade to be allowed in case of dispute. The wayleave rents to be subject to revision at periodical intervals, as this is essential if the terms of tenure are to be in perpetuity or for a long term of years.
- (*f*) Wayleave rents to bear some relation to the rentals which are received by the owner for the ordinary use of his land.
- (*g*) Compensation to be given and apportioned equitably by the tribunal duly appointed to all beneficially interested in the land.

Mr. Verni

- (*h*) All persons beneficially interested in the land on a given route in the event of disagreement to be convened at one and the same proceedings for the determination of the compensation if this is an arbitration or an appeal.
- (*i*) Damages occasioned in the execution of the work to be settled separately from the amount of compensation for the wayleave.
- (*j*) Compulsory powers to be granted for the cutting and trimming of trees.
- (*k*) Special provisions to be made for the grant of a compulsory wayleave in the case of owners who either cannot be found or are absent from the country, as in the Lands Clauses Consolidation Act 1845.

The second part of Mr. Chamen's communication deals with the abolition of the local authority's power of absolute veto on the question of the erection of overhead wires. The suggested clause except in one respect could not be improved upon and should finally remove all doubts as to the power of a local authority to prevent and obstruct the development of overhead transmission and distribution lines mainly on private property. There should, however, be some limit to the time allowed to the Board of Trade for a decision as to whether the consent of a local authority is being unreasonably withheld, which I suggest in such a simple matter should not exceed two months, and preferably only one month. I have given an example in my reply to Mr. Welbourn (page 361) where the time which elapsed in one such case was five months, and this is not greater than I would expect in ordinary cases if there is no limit placed upon it by law.

The short résumé by Mr. Gill of the National Telephone Company's experience in the matter of wayleaves illustrates very well the great difficulties which beset the path of the non-statutory undertaker who, without statutory assistance, seeks to provide a public service on any but the smallest scale, especially when, as in the case of the National Telephone Company, he deals with a service, viz. the transmission of intelligence, which the Postmaster-General carefully guards as his special prerogative. While the non-statutory authority, therefore, has the advantage in some cases as pointed out in this discussion, this is distinctly not one of them.

I am pleased to find Mr. Trotter endorsing the justice of an appeal to the Board of Trade against the veto of a local authority. His quotation of the special clause in the South Wales Electric Power Act 1904 shows that the principle has already been accepted by Parliament, and it should not be a very difficult matter to get it extended to other undertakings, preferably in a general Act.

It will be somewhat disappointing to others besides myself, to find Mr. Trotter expressing doubt as to the ability of the Board of Trade to undertake satisfactorily the adjustment of wayleaves. No such difficulty evidently presented itself to the Land Enquiry Committee, who in their report recommend that Government departments (which include the Board of Trade) should have the power to make an order for the compulsory acquisition of wayleaves for any purpose. I myself cannot appreciate wherein the difficulty lies, unless it be that the organiza-

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[*] In the words of the Prime Minister addressing a Labour Deputation a week or two ago: "The War presents an opportunity for the reconstruction of the industrial and economic conditions of the country, such as has never been presented in the life of probably the world. There is no time to lose, and I believe that the after the War settlement, is the settlement that will direct the destinies of all classes for generations to come. I am not afraid of the audacity of your proposals. I believe the settlement after the War will succeed in proportion to its audacity. The readier we are to cut away from the past, the better are we likely to succeed. I hope that every class will not be hankering back to pre-War conditions. Think out new ways. Think out even new ways of dealing with old problems. Don't always think of getting back to where you were before the War. Get a really new world."

[illegible] the Board of Trade is generally admitted to be [illegible] the electrical [illegible]. The fact that the electrical industry remains under the organization of the Harbour division of the Board of Trade, is in itself a sufficient indication of the importance it carries in Government circles.* It is not clear from Mr. Trotter's remarks whether he suggests that [illegible] should be invested with new powers to deal with compulsory wayleaves, or whether he would adopt the machinery of the Light Railways Act [illegible]. If it is essential that a local inquiry should be held, the Board of Trade might be authorized to appoint the Light Railway Commissioners to hold such inquiry, although it would appear that the Board already has this power under Section 2 of the Board of Trade Arbitrations, etc., Act 1874. But if the suggestion be that the procedure of the Light Railways Acts should be followed, which may involve two local inquiries, one by the Commissioners and one by the Board of Trade, and even contemplates a reference to Parliament at the discretion of the Board of Trade, which further incorporates the Lands Clauses Acts and provides for the settlement of the compensation by a single arbitrator and in some cases by the Commissioners themselves, the usefulness of these powers would be extremely limited for reasons which I have already elaborated in this reply.

[illegible]

NEWCASTLE LOCAL SECTION, 16 APRIL, 1917.

Mr. H. W. CLOTHIER : This paper is a timely innovation. It demands the removal of obstacles in the path of development and progress in the uses of electricity for the service of the community. The War has brought home most forcibly the need for more rapid progress. It is now recognized as a national matter, and I think the Institution will be foremost in directing its energies to the full in order to solve troubles and difficulties which in pre-War times had often to be borne by individuals and isolated sections of the industry. The author has clearly shown by the record of experiences that the need for reform in the matter of wayleaves calls for the most serious consideration of the electrical industry and the public in general. He finds that representatives of the [illegible] existence of [illegible]" in dealing with such matters. This is [illegible] deplorable, but it is nevertheless true that meetings of non-technical men are apt to be reticent and ultra-cautious in handling propositions with which they are not [illegible] than the community. Are not [illegible] some extent to blame for this state [illegible] not exist amongst them a corre[illegible] with the administration of the [illegible]. I consider the electrical [illegible] had we the inclination, to pay much attention [illegible] spirit."

[illegible] On page 330 the statement that [illegible] is free to erect overhead [illegible] the local authority needs some [illegible]. I think the author has hit on the main fact, [illegible] points out that it is impossible to [illegible] the whip hand, and the way in [illegible]

Mr. Burt

land. He does not deal with parks or land in front of and in connection with private houses. That is a different matter. At the present time a pole is not beautiful, and an unsightly row of posts in view of a mansion house certainly affects the value of that house. Taking the land as purely agricultural, however, the damage to the landowner is in the main nominal only ; it is the tenant who suffers most. A certain amount of land is spoilt and the tenant is clearly entitled to compensation. The time has come when compulsion for the acquisition of wayleaves for electrical purposes is really necessary, not only for the industry itself but also in the interests of the public. The War is producing effects on the public mind which will make it all the easier to get compulsory powers. Of course in all compulsion there is the very difficult question of the incidental costs. One knows that the costs under the Lands Clauses Act have always been a very serious addition to the cost of the acquisition of land. [illegible] the costs of the arbitration have to be borne by the undertaker. Under the Public Health Act the question of costs is entirely at the discretion of the umpire, which is a useful provision because it has the effect of making the owner a little less stiff in his demands. On the question of costs, the difficulty is to set up a competent tribunal which shall be fair to both parties and at the same time be able to deal with the matter at small expense. I would suggest for consideration whether it might not be possible for a Bill to be passed which would enable the parties in the event of disagreement to make use of the services of the experts in the Land Valuation Department as arbitrators in disputed cases. The head official in each district should have sufficient spare time and knowledge to be able to undertake impartially such arbitrations, which after all would not be very numerous. Such work might be made part of his official duties and his services might be available at a small fee or without any fee at all. Some such procedure would save money and, I think, produce a satisfactory result. I should imagine that in the ordinary case of a wayleave across a farm such an official would have the necessary local knowledge and be able after hearing evidence to give an equitable decision satisfactory to both parties. I think the suggestion that the compensation might be ascertained by an arbitrator appointed by the Board of Trade might prove much more costly, owing to the expenses and fee in connection with a special journey from London. I cordially support the sugges-

, Burton. tion that the undertaker should be empowered to enter upon the land and commence work under proper security before the payment is ascertained, and I hope that before long some machinery may be set up by which matters of this sort can be speedily determined at a reasonable cost relatively to the interest involved.

. Chrisp. Mr. T. **Chrisp**: In this district I have found two serious difficulties to contend with, namely, delay in negotiations, and the gradual increase in rentals. With regard to the landowner, it seems iniquitous that any one man should be able to hold up work of national importance, simply because he cannot make up his mind, for sometimes as long as 18 months. But to me by far the most important point seems to be the gradual increase in rentals. So far as the obtaining of consent to cross land is concerned, perhaps we are fortunate to have many large landowners in this district; at any rate I have always found their agents amenable to reason in this respect, and willing to do anything in their power to help us. The difficulty arises where we come across the small owner who demands an exorbitant price (and he is nearly always to be found on a route of any length). The question then arises whether it is advisable to divert the line at a great additional expense or to pay the rental demanded. Should the latter course be taken in order to save the extra expense, which often amounts to hundreds of pounds, what is the result? Other owners demand a similar rental the next time they are approached for wayleaves, and in this way the rentals have increased from time to time. It has often been said to me that everyone should be paid the same rental. I agree, provided they are all willing to accept a reasonable amount. In practice, what happens is that out of, say, 10 owners one may insist on a large rental and the others then have to be paid on the basis of the highest price demanded. Endeavours have been made to standardize the rentals in this district, but mainly owing to the above reasons very little success has been experienced. Whether the large landowner is justified in increasing his rental in order to come into line with others or not is perhaps a matter of opinion, but the fact remains that rentals are increasing and have increased to such an extent that in my opinion unless some such measure as the author has advocated comes into force, the efficiency and economy of national industries will be seriously handicapped.

idwin. Mr. F. G. C. **Baldwin**: My personal experience in the negotiation of wayleaves has been associated with easements required for telegraph and telephone purposes, and no doubt the difficulties met with are not dissimilar from those of power supply engineers. I have had an opportunity of judging the relative merits of carrying out wayleave negotiations, first without the assistance of any legal powers whatever, and secondly under the powers conferred by the several Telegraph Acts. Although there can be no doubt whatever that great advantages will accrue if the proposals contained in the paper are forthcoming, still it should not be expected that the whole of the difficulties which arise in obtaining wayleaves will disappear; and, furthermore, fresh difficulties will no doubt arise and will have to be countered. The author refers to the stipulations sometimes imposed by wayleave grantors. Occasionally these are of a curious, not to say ridiculous, nature. Mention of one only out of a considerable number which have come under my notice from time to time will suffice. Some years ago, application was made for permission to erect a line of poles across a large estate which could only be avoided by making a wide detour and incurring considerable additional outlay. After some delay, the owner reluctantly gave consent for the erection of the poles with the proviso that each should be painted in stripes of red, white, and blue, and that pulleys and cords should be provided so that he might be enabled to raise the national flag when he so desired. The poles were subsequently erected and the conditions imposed complied with. At a later period the grantor evidently became dissatisfied with the colours he had chosen and requested that the poles should be repainted blue and certain other alterations made. Mr. Baldwin.

Mr. J. W. **Laws**: Overhead construction is an essential part of electrical distribution, and the granting of the essential wayleaves ought therefore to be based upon some sort of logic or equity. Legislation is essential in the interests of an organization which has striven through the experimental stages of supply to the present position, and therefore neither an individual nor a local authority should have the power, either by imposing arbitrary conditions or absolute veto, to prevent the giving of supply. This, therefore, calls for immediate attention. It seems absurd in some cases for local authorities to compel a company to lay cables at a depth of 3 ft. while those in an adjacent district are laid at a depth of 2 ft. or 2 ft. 6 in. I am not concerned with the machinery which should be created in order to carry out what is required, but I think it ought to be possible to extend the principle of the Public Health Act 1875. If a local authority be empowered by that Act to carry water or sewerage mains through private land and the only question to be considered be the damage, it does not appear to be right that any company supplying electric power should continue to be subject to these restrictions. On the other hand, however, I believe that sooner or later the development of electricity supply will compel companies to adopt underground mains more and more; the Government must therefore in the interests of the community make electrical distribution by this method economically possible. Mr. Laws.

Mr. A. H. W. **Marshall**: It might be helpful if I gave one instance of the hampering of the electrical development of an important mining district by the arbitrary and unreasonable action of a large landowner. Some eight or nine years ago the company with which I am connected opened up negotiations for the erection of about 20 miles of pole lines in a district which was well adapted for overhead line construction, but their efforts were blocked by the owner of a large estate over which the greater part of the lines would have been taken. The only alternative was to lay cables in the public roads at a cost of about £30,000; on the same basis the district could have been served by means of pole lines at less than 60 per cent of this sum, so that there was an expenditure of about £12,000 which, so far as the company was concerned, was a sheer waste of money. Other disadvantages followed, in that the energy had to be transmitted over greater distances; and when the mains were loaded to their full Mr. Marshall.

[illegible] the development [illegible] pending the expenditure [illegible] Had pole lines been erected the capacity of the lines could have been increased [illegible] terms was that construction of the overhead lines would interfere with the amenities of the estate. In this connection I do not agree with one or two previous speakers that overhead line construction when well carried out is a disfiguration of the countryside. What has made it so in a great many cases is that the route takes a tortuous course to avoid property and to follow fence lines; where the lines can be erected straight from point to point there is to my mind no disfigurement. There is one point in the [illegible] it seems to me a fundamental one. On page 337 he says that "The arbitrator or valuer should not be allowed to take into consideration any saving in expenditure which is afforded to the undertakers by the grant of the wayleave." If this be so, it follows that the only rent to be paid is that required to cover the damage—permanent and temporary—which is likely to be sustained by the tenant or occupier; and consequently the landowner, if he makes full allowance to the tenant, does not get anything himself. This is scarcely equitable, as the undertaker can obviously afford to pay some part of the saving in expenditure which he makes over what alternative method is available, and the landowner is certainly entitled to some consideration for the use which is being made of his property. The question to settle is what is a fair rental, and as the whole [illegible] compulsory powers is to make it [illegible] to be secured by the undertaker at a price which will permit of the development of the electrical supply in the public interest, it is obvious the settlement of this price can only be left to some authority such as a Parliamentary Commission or the Board of Trade which is in a position to decide how far the public interest has to be served. The rental demanded by the landowner for the right of use of his property is in the nature of a [illegible] however capable he may be, as he has no basis to work [illegible] of land by compulsory purchase, as in that case the value of land is settled by what it could be used for for other purposes. I think that the author's recom- [illegible] for the fixing of both underground and pole-line wayleaves on some such basis as, say, one-fifth of the average annual rental per acre of the land, taken over a number of years, [illegible] and land rented at £2 per acre. It is an increase in value [illegible] mately 50 yards wide running the full length of the line; [illegible] be priced differently [illegible] waste of time and money, legal charges and otherwise, which are bound to follow the attempts of arbitrators, surveyors, and lawyers to settle equitable terms. As a reason for advancing the particular sum which I have mentioned, I may say that it is approximately the rental at which one of the largest land-owning trusts in the country, whose management has considered the matter both from the point of view of their own interests and that of the public utilities, is prepared to grant wayleaves.

Mr. Marshall

Mr. C. TURNBULL: One of the difficulties in getting Acts of Parliament through, giving power to run overhead cables, is that so much attention is given by the public to any electrical accident. Far more people are killed and wounded by slipping on orange-peel and banana skins than by electrical accidents, and thousands more by motor-car accidents, but Parliament passes no Bills to prevent such accidents. Yet a single electrical accident, even if caused by criminal action of the person who suffers, is sufficient to block the way to progress in wayleave legislation for a long period. Probably the best way to get people into a more friendly frame of mind would be to convince them that they would save money if wayleaves were freely obtainable, for the benefit of electricity at cheap rates would eventually filter through to the whole community. It is wonderful how soon the average man's opposition fades away if he thinks that he is going to gain by the change. Mr. Burton has made a valuable contribution on the arbitration problem, and we must hope that something will be done to give effect to his proposals. It would save much of the cost of arbitration if the rule were that each side paid its own expenses. Where necessary, the arbitrator could allow for this in his award; but the uncertainty attaching to such allowance would prevent people from increasing the costs in the way that they now do, when they feel sure that the other side will pay all expenses. To give full effect to this we must find means to ensure that it is not to the advantage of the arbitrator to have long and costly arbitrations to decide simple problems.

Mr. Turnbull

Mr. C. E. ELDER: The obstruction and delays which local authorities are able to place in the development of overhead schemes, by virtue of the powers conferred on them by antiquated Acts of Parliament, are entirely out of touch with the spirit of "push and go" which is a marked feature of all healthy electrical power concerns. There is room for improvement in regard to consents, and the author is very moderate when he pleads for a further concession in connection with the question of appeals, and a time limit for notices, etc. Surely the consent of the Board of Trade to erect a line on private land, and the permission of the landowner, are sufficient authority without having to plead for the further consent of the local authorities, who, as the author points out, are in many cases ignorant of the powers which they possess. I think the author's suggestions for dealing with wayleaves are based upon reasonable and practical methods, and I have no doubt that his expectations will soon be realized in this direction. If we have to continue under the present conditions, the position will, I think, become impossible, as the landowner or tenant will demand more compensation than ever, owing to the increased value of arable land. I should like to say a word on behalf of the farmer on the question for compensation for pole standage. It will be

Mr Elder

. Elder seen from the author's remarks on this point that it is possible to fix up a scheme with the landlord wherein the farmer or tenant is left out of the bargain. On behalf of the farmers in general, and the mains engineers in particular, let me say that such arrangements are absolutely unsatisfactory for smooth working between these two parties, and I give this from practical experience. Farmers can be a great help to the mains department in many ways by coming to their assistance with ladders, carts, etc., in times of trouble, but if the trouble were to occur on a farm when no compensation is allowed, it is certain that little help would be forthcoming. In other words the farmer would be absolutely dissatisfied, and would not consider our interests in any way. It is an important item to have satisfied farmers on our pole-line routes.

. Hunt. Mr. F. O. Hunt: There seems to be every prospect of history repeating itself. In the early development of railways there were instances where, owing to obstruction by landowners, lines had to be diverted. The descendants of those obstructors are now regretting the "dog-in-the manger" attitude of their predecessors, because the property has missed much of its share in the resulting development and in some cases centres of population have been diverted to other districts. This is a point which might well be utilized in negotiating with stubborn objectors. As regards the route to be taken by pole lines, I must sympathize with the owners and farmers. A row of poles across country without regard to fences increases not only the amount of wasted ground but also the cost of working. This is especially the case where power ploughs are in use, and presumably the pole lines themselves may lead to an increase in such methods. It is necessary therefore that pole lines should be so arranged as to interfere as little as possible with cultivation.

egory. Mr. R. W. Gregory: This paper can be considered to be the nucleus of an appeal to the Government to grant certain terms of preference to suppliers of electric power in their dealings with owners of certain existing rights, and inasmuch as this action may be held to be opposed to the doctrine of economic freedom it behoves us as suppliers of electric power to show that the granting of this appeal will enhance the prosperity of the nation and will at least do no harm to the few whose rights we wish to curtail. The arguments in favour of compulsory wayleaves can, I think, be divided under two headings, namely, (1) economic, (2) æsthetic. The author has not restated the economic argument. It can be done fairly well, I think, in six sentences. (1) The amount of power consumed by a manufacturing nation in a given time is an index of that nation's income in that time. (2) The more cheaply power is to be obtained the more it will tend to be consumed and the greater the tendency for the national income to increase. (3) The fact that there exists a large, varied, and growing demand for electric power from the mains of public electric supply authorities is a proof of its cheapness when so supplied as compared with other forms of power production. (4) Public electric power supply authorities who are able to generate and supply power cheaply and to supply power economically in its cheapest form are therefore of national utility. (5) Unreasonable hindrances to the supply of cheap electric power to desirable consumers are against the national interests. (6) The unreasonable withholding or obstruction of rights-of-way for electric mains is a hindrance to power supply, and in that this action either results in an increased cost of connection—which means decreased economy, or delay in supply—which means decreased consumption of power—is against the national interests. Mr. Gregory.

The owner and occupier of the land by granting a right-of-way are entitled to receive between them: (1) Compensation for their inability to put the land occupied by electric mains to the use it was put to before occupation. In practice this compensation can be split up into: (*a*) loss of profit on agricultural produce due to (i) reduction of area of cultivation, (ii) increased cost of cultivation due to obstructions; (*b*) or, if the owner reduces the rent to cover (*a*), loss of rental value of land due to inability to cultivate and increased cost of cultivation; (*c*) damages to crops, fences, roads, etc., during the construction period and from maintenance. (2) An acknowledgment of the owner's right to the land — a nominal sum. In addition there is an extra which is "extra-legal," and which might be called "an acknowledgment of utility," the argument for which is as follows: It is as well to remember that from the landlord's point of view he has as much right to expect to make money out of a demand for wayleaves as he would from a demand for building sites, or a demand for mining rights. The national utility argument can be made to hold in these cases as well as in the case for wayleaves for mains. It is therefore advisable to recognize the very human wish to profit by a lucky windfall and to express a willingness to pay both the landlord and tenant more than they are actually out-of-pocket. This extra sum might be called "acknowledgment of utility" as it is really money awarded to people in acknowledgment of their willingness to be of public service. This fee if recognized by the supply authorities would speed up the workings of any State machinery that they may be allowed to operate. I should say therefore that the rates for items (1) and (2) should be settled by the State as suggested by the author. The amount of "acknowledgment of utility," however, should be fixed by the electric supply authority itself, should be a standard throughout its area, and should be publicly known.

The author has mentioned the probable state of affairs after the War: the need for the very maximum of manufacturing output combined with the strictest economy in capital. Economy in capital as applied to extensions to the distribution of electric power must mean a large increase in overhead electric mains, many of which will be run at higher pressures than generally obtain at present, and this brings us to the second argument in favour of compulsory wayleaves, namely, the æsthetic. It is not within the province of engineering to aim directly at satisfying that vague and indefinable sense generally known as beauty, but engineers in their structures should endeavour to combine sound physical engineering with an appearance of neatness and fitness. The natural function of a pole line is to connect two distant points electrically by the shortest possible route. Pole lines should therefore be dead straight if they are to possess the property of fitness. If they deviate from the straight they should do so only to get round an obstruction which obviously obstructs. A road or a footpath should not be [illegible] way. We suffer motor-cars and level-crossings on our [illegible] of transport to the welfare of the nation. The recognition of the equal national importance of cheap power should prevent many of the short-sighted hindrances to proper facilities for electrical distribution which obtain too much at the present time.

Mr. Beard. Mr. J. R. **Beard**: Although the instances of obstruction quoted by the author are in themselves sufficient justification for his recommendations, it may still further strengthen his case if I refer to some additional instances which I have come across. In the first of these it was desired to duplicate the supply to an important industrial area and the only economically possible way of doing this was by means of an overhead line across country. The most direct route passed through the centre of a narrow estate some five miles long and the owner absolutely refused to consider a wayleave, even for a single pole, and declined even to discuss his objections or means for meeting them. There could not be even the usual excuse that it spoilt the "amenities" of his estate or the view from his house, as he did not live on the estate, which consisted of ordinary agricultural and pasture land in an uninteresting district where the tenants would have raised no objection. As a result the line had to be diverted some three miles. This diversion caused further delay, since the line had then to cross an estate whose owner was temporarily in New Zealand. The delays in communicating with him and settling terms, added to the previous delay, resulted in over a year passing before any work could be commenced. In the latter instance the owner was not in any way at fault, but there should be some procedure which would enable [illegible] owner in a reasonable time. This would be quite possible if the owner had no absolute veto. Passing from particular instances to a more general one, it may be of interest to note that when the first extensive high-pressure distribution system in this country was being designed (that in the county of Durham) the most suitable voltage was about [illegible] voltage was not practicable on underground cables. Owing [illegible] was settled upon. At that time this was considered a very bold step for underground cable work and there is no doubt that it was the maximum which it would have been wise to use at that stage of development. However, as the [illegible] difficulties and delays over wayleaves. I should like the author to define if possible the various degrees of ownership of land which can exist. Is the landowner really the absolute monarch we are all brought up to think him or has he his limitations? I should also be interested to know whether any previous attempt has been made, either in power company Bills or otherwise to restrict his absolute veto as regards wayleaves. Incidentally in connection with the second paragraph in the right-hand column on page 331, I should like to ask why the local authorities have been given the powers they refer to; it is obvious that they should not usurp functions which belong to the Board of Trade, but I assume that since they have certain powers they must have been given them for a purpose. From the discussion before the Institution in London (page 346) it seems evident that engineers are already agreed that some modification is necessary to the existing law on wayleaves. Our most important duty at the moment is therefore to convince the non-engineering public of the justice of our case. From this point of view I think in all our discussions it should be made clear that such additional powers would have a tendency to lessen the effect of an overhead line on the amenities of a district. An overhead line with carefully levelled and properly vertical poles running across country in a straight line is not a distasteful sight; but under present conditions routes are far from straight; in fact, I have heard them aptly described as a number of dogs' hind legs in series. Such a zig-zag line is certainly not beautiful, and the twists and turns mean frequent guys and tend to pull the poles out of the vertical. Further, long straight runs would enable longer spans to be used, which would not only provide an opportunity of cheapening the construction but would add to the appearance. Another important thing is to bring home to the general public that additional powers are not asked for in the name of private undertakings but by undertakings working under special parliamentary powers and with their public nature recognized, either by actual public control as in the case of municipalities, or else by restrictions as to the rates of dividend and as to the maximum price which can be charged. It should become the regular custom to use the expressive American phrase, "public utility undertakings," and I would suggest for instance that in the case of companies of this type the share quotations should all be grouped under such a heading as "public utility companies." A further point which should always be borne in mind when considering the desirability of powers for the compulsory acquisition of wayleaves is that due to the enormous waste of wealth during the War it is more than ever important to do everything to conserve our capital resources. If a supply undertaking is prepared to pay a rental or a wayleave it follows that the capital value of the land over which the wayleave is required has been increased due to the fact that it has been found desirable to carry electric mains across it. If permission for such a wayleave can be refused the enhanced capital value of the land is wasted and in addition the undertakings have to bear the increased [illegible] the route, which expenditure is from the national point of view quite unremunerative.

Mr. H. [illegible] that the Acts and Regulations governing the distribution [illegible]

r. Bridges. of caution, because to some extent electrical power was then an unknown quantity; but that time has passed, and the present is the time for action, and not for the adoption or retention of cautious measures. The idea of running overhead transmission lines and underground cables across country for long distances is comparatively new, but the transmission and distribution of electrical power by these means is essential to economical industrial development, and, as the author points out, the time has arrived when serious consideration must be given by our legislators to assist in removing all obstacles in the way of the wheel of progress. The parties to whom appeals are made for consents and wayleaves must be brought to realize that their first duty is not to put the brake on the wheel of progress but to accelerate its motion. I fully agree with the author that a time limit should be determined in the matter of obtaining consents, and this limit should be as short as possible; as one month is considered sufficient for the laying of cables in public roads, there does not appear to be any reason why this should be extended for private property. This concession would be an immense advantage in accelerating the distribution of electrical energy. After the War is over, every effort will have to be put forward to accelerate the development of industries of all kinds, and this can best be done by the adoption of electrical power. Here, then, is the necessity for unrestricted distribution on a large scale over the country. The necessity having arisen, the present obstructions in the way of obtaining consents and wayleaves must be swept away. The author has referred to the fact that a considerable number of individuals and private and public bodies hold the view that company undertakings are merely a source of private profit and are not for the good of the community at large. If this view can be upset there is no doubt that many difficulties in the way of obtaining consents and wayleaves will be removed. I will instance a case of recent date, where an overhead line of many miles was required to be run in order to give a supply to an important munition works. Because it was realized that the erection of the line was of national importance, very little difficulty was experienced in obtaining the necessary consents and wayleaves. The question of rent is a very important one, and some standard should be adopted as a basis in order to create uniformity.

r. Hunt. Mr. O. W. HUNT (*communicated*): The great objection to wayleaves, from the land agent's point of view, is frequently the "lay out" of the supply line. The promoters naturally choose a direct route, and this frequently cuts up the land in a very objectionable manner. Poles fixed in arable land interfere very much with cultivation, and this appears to be a matter of increasing importance owing to the growth of motor traction and steam cultivation and possible introduction of electric power cultivation. The urgent Government demand for the ploughing up of existing grass makes it imperative that the fact of land being at present in grass must not be taken as a criterion that it will not have to be dealt with as arable land. Even when pole lines follow the hedgerows, there are legitimate objections. I have not had experience of power mains, but for telephone purposes the lopping of trees is frequently such as to render them absolutely useless as timber. Personally I never allow any trees to be touched without personal sanction or sending the Mr. Hunt. estate forester with the men who do the work. I do not think much of the proposal that the district valuer should fix the amount of rental, etc., as one knows from practical experience that some of these gentlemen have not a sufficiently general knowledge of the subject. Many of them are men with little knowledge of agricultural property, and the Land Commissioners as at present constituted are not a body that I think would meet with anything like general acceptance.

Mr. Vernier Mr. C. VERNIER (*in reply*): I have listened with much interest to the discussion, and I am pleased to find that we have had the same unanimous expression of opinion here as in London and in Yorkshire on the pressing need for legislation on this question. Mr. Clothier, in opening the discussion, referred to the attitude of local authorities in dealing with matters of importance to the communities which they represent, and it is true that they are in some measure handicapped in this by having to handle questions which they do not understand. This does not prevent some of these local authorities, however, from interfering in such matters with all the assurance which lack of understanding only too often commands, and from declining to enlist the assistance of the Board of Trade, who does understand them. Moreover, evidences of a lack of public spirit are unfortunately not always confined to electrical questions, which to the layman always seem wrapped in mystery, especially if these matters should involve relations with neighbouring authorities.

Mr. Burton lays stress on the fact that the main difficulty in negotiating wayleaves is that it is impossible to bring pressure to bear on the landowner. The President in the London discussion also referred to this point, and showed that where pressure can be brought to bear by introducing questions of self-interest, serious difficulties can usually be got over. Mr. Baldwin has quoted an excellent example where the contrary obtains.

I support the suggestion made by Mr. Burton that the experts in the Valuation Department, i.e. the District Valuers, should act as arbitrators in disputed cases, and I have already made a reference to this and to the cost of Board of Trade arbitrations in my previous replies.*

As Mr. Chrisp remarks, it is the smaller owners who are usually the most troublesome, not only on account of delays but also owing to their exorbitant demands. I am not sure how far the considerations put forward by Mr. F. O. Hunt, on the question of history repeating itself, and by Mr. Turnbull, may weigh with landowners, but they are not entirely ignored by some, although unfortunately very few of the more enlightened of the larger landowners and their agents, if only to the extent of perceiving that the introduction of electric power in a district is beneficial to the development of that district, and eventually to themselves. Having said this, it is also necessary to add that they do not carry their conviction to the point of allowing undertakers to mortgage the future by quoting them low rents. The smaller landowner, because his estate is small, has not the same incentive of personal interest, and may (as he thinks) reasonably argue that if there is any advantage likely to accrue in this way in the immediate neighbourhood, it is his neighbour, the large landowner, who will chiefly benefit. But, more often than not, such

* *Ante*, page 300.

a thought never occurs to him, and the applicant who made such a suggestion would [illegible] be met with derision.

The steadily increasing cost of wayleave rents has also been dwelt upon by Mr. [illegible], who, like myself, is somewhat apprehensive at the limit to which they may soar with the excuse of the permanent increase of taxation and high prices of all commodities which will remain with us for many years after the War. As he has indicated, it only needs one sufficiently obstinate landowner on a route to cause a general increase of wayleave rents all round, and the process can of course be pursued *ad infinitum.*

Mr. Baldwin has shown by his single example of the ridiculous conditions a particular landowner was able to impose, how utterly helpless important public service undertakings are in a matter of this sort, which places the squandering and waste of the nation's capital resources at the mercy of the whims and fancies of privileged persons, whether sane or bordering on the insane.

One or two speakers have touched upon one point which has brought forth replies from Messrs. Marshall, Gregory, and Beard in referring to the unsightliness of pole lines. Mr. Gregory has, I think, expressed most clearly the engineer's and craftsman's view of what constitutes beauty in this connection, and these members have laid the blame upon the difficulties of obtaining straight runs for overhead lines. I think that this accounts for most of the ugliness complained of. There is, however, something to be said for the other point of view, as many of the owners of such lines do not expend one penny more upon them than will merely satisfy strictly utilitarian purposes. For example, how many of these owners take the trouble to survey the ground and grade their pole lengths so that the wires do not have to follow the ups and downs of the contour of the ground? A line which not only winds about over the surface of the ground, but whose conductors perform the same angular displacements in the vertical plane, with poles out of plumb and cross-arms not level, is admittedly not a thing of beauty. If these be the lines complained of, I agree, and I sometimes wish there was a public censor of pole-line construction to deal with them; but if these remarks are applied to a really well-built line, what we engineers would be pleased to call an engineering job, I must differ. These things are also largely a matter of habit. I have no doubt telegraph lines went through the same criticism in their early days—and I particularly observed the criticisms did not include them—while most of us are aware that the same criticisms were levelled at overhead trolley wires in many of our towns, yet to-day no one ever takes any notice of them; in fact a main road without telegraph wires would appear to many if they were suddenly removed, almost bare and uninteresting. I agree that overhead lines mark what I believe will eventually prove to be a transitional stage in the development of electrical transmission, and but for the recognition of this fact, I would have had no need to emphasize so strongly the necessity for national facilities for underground cables. The [illegible] of a well-laid underground cable system will always make its adoption attractive for [illegible] if its cost can be afforded, and too much should not be made of the greater difficulties in producing very high-voltage cables up to the limit likely to be needed in this country, difficulties which I do not think are insoluble. I am not going to predict how long this transitional stage is likely to last; all I can safely say is that the appalling cost of the present War is likely to prolong it for very many years longer than otherwise. This is because electric supply undertakings, like other similar undertakings, viz. gas, water, etc., obviously require a very large initial expenditure of capital in order to establish their works, but are also subject to the economic condition of increasing returns or diminishing costs. Unless, therefore, capital can be cheaply obtained, or alternatively more economically used, as by providing practically the same service with an overhead line costing only about one-half of an underground cable, the undertaking cannot fairly get past the initial stages of its development, because it can never raise sufficient further capital on good terms to enable that stage of its development to be reached when increasing returns become apparent. We have but to look at the past history of many of our large power companies to appreciate how this has been their main difficulty, accentuated as it was by their exclusion from the large centres of population. It is only increasing returns, in other words a well-established and prosperous business, that will enable our undertakings to go in extensively for the more expensive underground cable construction.

Messrs. Marshall and Beard have given examples which go to emphasize still further the great need for putting this question of wayleaves on a satisfactory basis from the national point of view. It cannot by any stretch of imagination be maintained that for an individual to cause a sum of £12,000 to be expended unnecessarily, or the compulsory adoption of an uneconomical voltage of transmission, is matterless from the point of view of the national interest. The annual interest on the above £12,000 must remain at the caprice of this individual as a permanent charge on all the consumers of that undertaking, and this is only one example. Further, what is still more important, it might for all the remedy the supply undertakers had at hand, have deprived those consumers of a supply altogether by making the scheme financially impossible. Mr. Beard's example is equally to be deplored, for all the consumers over practically a whole county must suffer the loss of economy which has resulted from the adoption of too low a pressure, a loss which must be measured not merely by loss of efficiency in distribution, but by the very much greater capital expenditure necessary to provide further supplies as the loads increase beyond the capacity of the present main cables.

Mr. Beard has asked how far the landowner is absolute monarch, or if he has limitations to his right of ownership. In a matter of this importance, which lies at the root of the whole discussion, I think I cannot do better than quote authorities, as under the doctrine of individualism which prevailed from the beginning of the last century up to the outbreak of the War the right of private property, and the right of its possessor to do as he likes with it, have come to be commonly regarded as well-nigh inviolable. I therefore give the legal, ethical, and economic views on this question.

*Legal view.**—"It may not be amiss to point out one or

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* The Land Laws, by Frederick Pollock, [illegible]

Ir. Vernier. two of the general features in which the legal conception of ownership and rights over land are at variance with the popular ones. It is commonly supposed that land belongs to its owner in the same sense as money or a watch. This has not been the theory of English law since the Norman Conquest, nor has it been so in its full significance at any time.

"No absolute ownership of land is recognized by our law books, except in the Crown. All lands are supposed to be held, immediately or mediately of the Crown, though no rent or services may be payable, and no grant from the Crown be on record. On the other hand, the law is equally far from countenancing the belief that there is land which belongs to nobody, and is free to all the world. Some such belief is probably held by most people who are not lawyers. But in England, it is not legally possible. Land may be subject to public rights of way, rights of common and to a great variety of private rights. It may be worthless for all purposes except those of recreation, and the owner may be undiscoverable. But an owner there must be somewhere; the Crown in the last resort if no other is forthcoming."

*Ethical view.**—"As it (the State) sometimes usurps or delegates to private activities forms of business that may be carried on by individuals, so its legal status is that of a single subject among other individuals or corporate subjects. At times it has to protect its own rights against those of others; and at times it must yield when the legal order which it has established recognizes the rights of individuals as superior to its own. From this relation of the State to individual citizens is derived its further relationship to private property. It is not merely the first of property holders, but it has a power of far greater importance—that of regulating all property relations and in so far as they are in accord with the order it has established protecting them. In so doing the State assumes sovereignty over all property. It asserts this right with especial force by claiming, whereever it deems such a proceeding essential for the interests of society, the privilege of appropriating property itself. Thus the right of expropriation, which belongs directly to no corporation but the State, is a plain intimation to the individual that with all his earnings and possessions, he is working in the service of the whole."

Economic view.†—"If then social utility is the real justification of private property, it is clear that the extent of private property rights must find its limits in social considerations. The right of private property is a privilege conferred upon individuals by society. It is recognized as beneficial in general because of the consensus of opinion that in the main better economic results can be secured by the application of the principle of self interest. In the present stage of the evolution of human nature, private property constitutes the chief incentive to better and greater production. The test, therefore, is always the social test.

"In certain cases where the results of private property are clearly opposed to the social interests, society is justified in restricting the extent of the property right. Thus, the private ownership of patents and copyright, which is everywhere limited to a term of years, thereafter lapsing in favour of society at large.

"Property rights may be classified under several heads, Mr. Vernie but the only one with which we are chiefly concerned is the 'right of use.' This not absolute. As against the doctrine of 'vested rights' the theory of 'eminent domain' is a form of social control which operates in favour of the principle of public utility. Apart from this, the individual right is subject to social restrictions, e.g. a man may not use his property so as to create a nuisance to his neighbour. Economic progress is bound up with the institution of private property, and yet society is asserting a claim to be heard in its control and disposition. We are beginning to realize the duties as well as the rights of wealth.

"This moral obligation is based upon the sound economic conception of social utility as at once the justification and the limitation of private property."

Mr. Beard further asks why the local authorities have been given the powers referred to in the paper and whether any previous attempt has been made to restrict their absolute veto. I have gone to some trouble to elucidate the first of these points, but without much positive success. Mr. Chamen in his communication to the London discussion (page 351) says that it is unreasonable to suppose that it was the deliberate intention of Parliament that the local authorities should have such powers. I am inclined to think myself that the wording of Section 10 (*b*) of the Schedule to the Electric Lighting (Clauses) Act 1899, was deliberate, and it appears to me that what led up to it was the erection of some 100 miles of 2,000-volt overhead mains over the house-tops in the Bond-street area of London during the middle eighties—what is known as the Grosvenor Gallery installation—which made the Board of Trade and the local authorities apprehensive that similar networks might spread in towns all over the country.* The fact that the 1899 clause lays such stress on the consent of the local authority and of the Board of Trade being necessary "except within premises in the sole occupation or control of the undertakers" would seem to support this view, and doubtless the possibilities of overhead transmission were not at that time fully appreciated.

The report and minutes of the proceedings of the Institution Committee on Electrical Legislation, referred to by Mr. Woodhouse (page 347) in the London discussion, do not throw very much light on this point. This Committee sat in 1902 or within a very few years of the enactment of the Electric Lighting (Clauses) Act 1899, but at that time, although a great deal of discussion† took place on the question of overhead wires, the criticism is chiefly directed at the Board of Trade, which was alleged to be opposed to the use of overhead wires altogether.

There is, however, a reply in Colonel Crompton's evidence‡ which brings in the local authorities as follows:—

> "I am not blaming the Board of Trade at that time (1882 onwards). It was the local authorities who then more than anybody else stopped the overhead wires. It was the local authorities who brought pressure on the Board of Trade. I was not in the secrets of the Board of

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* "Ethics," by Prof. W. Wundt, p. 259 (Swan Sonnenschein & Co., 1901).

† Paraphrased from "Principles of Economics," by Professor E. R. Seligman, Columbia University, pp. 134 *et seq.* (Longmans, Green & Co., 1916).

* There are good reasons why a local authority should have the right to object to overhead wires in towns, which is why I have excluded such wires from the scope of the paper (p. 329).

† See Questions Nos. 101 to 103, 139 to 143, 156, 163 to 164, 182 to 188, 210 to 216, 279 to 286.

‡ Question No. 188, p. 41.

[illegible] put up anywhere."

[illegible] wires along or across streets, the Board of Trade and the local authorities could not have prevented overhead wires [illegible] account of the ambiguity of Section 14 of the Electric Lighting [illegible] in fact prohibit overhead wires anywhere without [illegible] of the local authority, and, while statutory [illegible] may have taken a contrary view, they could not proceed in the face of the opposition of the Board of Trade. [illegible] Gallery installation belonged—could not be interfered with at the time, but when the Electric Lighting Act of [illegible] with the situation which had arisen. While these explanations appear to me to be logical deductions from the [illegible] from Colonel Crompton's reply, the whole subject was [illegible]

In reply to the second part of the question put by Mr. Beard, I have not seen the minutes of the evidence given before Lord Cross's Committee in 1898, but I have no doubt efforts were then made to limit the local authorities' power of absolute veto, and as I have already stated, this right of absolute veto was shortly afterwards withdrawn from a rural district council in Power Companies Acts.

Mr. Marshall has made an excellent suggestion that [illegible] based upon the rental received for the land, and he gives details of such a scheme which has been adopted by one of the large land-owning trusts. Assuming that the scale he mentions includes the compensation to the tenant as well as to the landowner, I can only say that if all landowners looked at the matter in the light of this trust, and on such a reasonable and fair basis, supply undertakers would have no cause for complaint. I would suggest that for underground cables a figure not exceeding one-half of that given for overhead mains would be ample. The difficulty I apprehend would be in getting such a simple [illegible]ted in an Act. It has never [illegible] provide machinery to settle disputes in [illegible]

[illegible] the use of electrical [illegible] are well known, [illegible] engineering circles, and one [illegible]

Mr. Vernier

govern compensation, to which he adds a suggestion that supply authorities should voluntarily make an extra payment not strictly demanded by the legal requirements [illegible] acknowledgment of utility."

Mr. Marshall also appears to suggest some such payment when he says that the landowner is certainly entitled to some consideration for the use which is made of his property. So long as it is understood that this payment is in the nature of an "extra legal" payment, for which the supply authorities should receive full credit, I think the suggestion is a very good one, and would assist in smoothing the way for the undertakers. This would necessitate that the compensation allowed to a landowner for the use of his land—which usually would be purely nominal—should be dis-associated entirely from any inflation on account of the land being utilized compulsorily. There is no additional compensation recognized in our legislation for the fact that land is taken compulsorily. A practice has, however, grown up among arbitrators in compensation cases under the Lands Clauses Acts of allowing a further 10 per cent on the purchase money, which is probably with some such intention. In some recent Acts,* however, the arbitrator is expressly forbidden to make any additional allowance on account of the purchase being compulsory. Because the landowner's damage is purely nominal and provided it is assessed at its proper value, I think that supply authorities would be quite willing, and even anxious in their own interest, to make this "extra legal" payment.

I welcome Mr. O. W. Hunt's remarks giving the land-agent's point of view. The statement also made by Mr. F. O. Hunt that poles in arable fields seriously interfere with cultivation, is commonly advanced, and as matters would not usually be forwarded by saying the things which are in one's mind while such one-sided negotiations are in progress, I gladly take this opportunity of giving them here. If there is one circumstance when this argument is used which is calculated to provoke, it is when a landowner or his agent who has quoted a rental for poles in his fields which would go a long way to rent whole fields, arable or otherwise, calmly says when going over the route: "This is an arable field, and I cannot have any poles in this field." He then suggests that the line should be erected to a chequer-board pattern, or that the poles be placed in the hedges, irrespective of the length of spans, one of which, for instance, might be a quarter of a mile long, followed by one of only 50 yards. Sags, pole lengths, stresses, etc., do not trouble him, because he does not understand them. At such a time it is very necessary to enlist one's best powers of diplomacy, persuasion, and tact, in order to secure a line which satisfies somewhat the sense of "fitness" and avoids the freakish so well commented on by Mr. Gregory. That poles are an obstruction and cause inconvenience and some increase in the cost of working arable land is clearly admitted, and throughout this paper and the discussion upon it the need for a full compensation to the party who suffers these things has plainly been insisted on. In this matter, I think we have shown a greater sense of justice than some of the landowners themselves, who, while recognizing and laying great stress upon the inconvenience and

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[illegible]

* [illegible]

Mr. Vernier. loss, do not hesitate to treat the tenant farmer in the manner frequently complained of by them to Mr. Elder.

Not the least of the advantages of an Act dealing with compulsory wayleaves would be to put a matter of this sort upon a proper basis of justice and equity. Such difficulties mainly arise because of the extraordinarily exaggerated value placed upon the land by its owner, and I think it will be well in order to form some idea how far the landowner's complaint is well founded, if we get down to actual figures.

An up-to-date heavy power line is usually carried on **A** or **H** poles measuring 4 ft. 6 in. across the legs at the ground-line, and these poles are usually spaced 80 yards apart. If we allow that a diamond-shaped piece of land 8 ft. across at the pole and 18 ft. long in the direction of the line is put out of cultivation with horse ploughing, this is a much more liberal allowance than I have found farmers voluntarily leave uncultivated around such poles. The area of this piece of land is 8 square yards, and as the poles are 80 yards apart, exactly one acre of arable land is put out of cultivation on a route of 27½ miles of line, assuming the land to be wholly arable. We could fairly assume that at least half the land would be pasture—it is nearer to 60 per cent of the whole area under crops and grass for the whole country—so that this length could easily be increased some two or three times, i.e. up to between 55 and 82 miles of line per acre. But even if we neglect this assumption, the value of the arable land put out of cultivation on the basis of its rental at, say, £3 per acre does not exceed 2s. 2d. per mile of route, or only roughly one-half to one-third of this if we allow for pasture, while if we allowed for heath and moorland as well the figure would be still smaller. With tractor ploughs it is certain that the amount of land that will remain uncultivated will be considerably increased, but even if we quadruple it, the figures still remain absolutely insignificant.

Some landowner may say that the rental of the land is not at all a proper basis to take in a matter of this sort, and that what we ought to take is the value of the crops which might be raised upon this land. I may say that this is no fanciful suggestion; it has actually been put forward seriously by a farmer. Leaving aside the point that if the land is uncultivated, at least no hand labour, manure, or seed is expended upon it, it would have been a very good crop (except potatoes) that would in pre-War times have realized £8 per acre. At this figure, what does the loss of crop amount to? Not quite 5s. 10d. per mile of route for horse ploughing, or 23s. 4d. per mile of route if we assume that tractor ploughing leaves four times the amount of land, viz. 32 square yards per pole uncultivated, and also that the whole of the land along the route is arable. These figures, I think, are quite sufficient to indicate that the value of the land or crops which is lost owing to inability to cultivate the land as if the poles were not there, is so small that the landowner's objection cannot seriously be substantiated. This loss, in any case, falls upon the undertakers, as also all damage arising from the existence of the line however it may arise. There only remains, therefore, the question of inconvenience in working, but as this depends almost entirely on the amount of land left uncultivated around the poles, it really comes down to a question of the value of this land, which I have shown to be scarcely worth discussing.

Mr. Trotter remarked in his contribution to the London discussion (page 472) that the inconvenience to a householder of a pole planted in the footway immediately opposite his front door is not to be estimated by the sectional area of the obstacle. Granted, but that is not the whole point, as the householder has to suffer the inconvenience whether he likes it or not (and that too in this case without compensation) if the pole is placed there by a statutory authority whose powers have been granted in the public interest and because the public interest comes first.

Mr. Gregory mentioned railway level-crossings. Here, again, all users of the road suffer inconvenience from the existence of gates across the highway, because it is in the public interest that railway facilities should be provided. Must we then consider landowners and farmers to be such a privileged section of the community that their convenience must come even before the public and national interest? It is only the reverence enshrouding everything connected with the ownership of land which enables landowners to put forward such claims with some show of reason. They will doubtless henceforth, in view of the greater necessity for increased food production, cry out against the loss to the country in putting arable land out of cultivation; whereas in fact the loss to cultivation of only some 400 acres out of a total of some 11 million acres of arable land would be sufficient to enable anything from 10,000 to 30,000 miles of overhead lines to be erected with incalculable benefit to the industries of the country, including agriculture itself, and to the health, wealth, and strength of the community.

The further question of tree cutting mentioned by Mr. O. W. Hunt is not one that need cause any anxiety to the landowner or his agent, whose assistance in sending experienced foresters to do the work is usually very much appreciated; but with power lines it is not so much a question of lopping trees as of cutting them down altogether in order to provide for the safety of the line and of the public. While landowners frequently raise objections to the removal of trees, farmers, on the contrary, often welcome it. It is indeed not without interest at times to find the farmer's opinion and that of the land-agent, who claims to be safeguarding the farmer's interest, in conflict. I have on occasion seen a land-agent objecting most strenuously to poles in arable fields to which the tenant farmer who was present raised no objection whatever.

YORKSHIRE LOCAL SECTION, 25 APRIL, 1917.

Mr. Woodhouse. Mr. W. B. WOODHOUSE: To supplement the remarks which I made in the discussion of this paper before the Institution (page 347) I should like to say that in addition to the compulsory powers which the Post Office have for wayleaves, the Postmaster-General has obtained in the majority of Tramway Acts of recent years compulsory powers to fix his wires to the tramway standards on reasonable terms. Those powers must be very valuable in narrow streets, and in some cases must be essential. There is another case where apparently powers are necessary, and that is—this relates rather particularly to underground mains—in the case of streets dedicated to the

Mr. [illegible] public but not taken over. In recent years a very large number of Gas Acts have contained a provision that in any street laid out and dedicated to the public, and not taken over by the local authority, the undertakers may lay gas pipes to supply the houses in that street. That is a valuable power, and I think a very necessary one.

Mr. Johnson. **Mr. T. B. Johnson**: I think that the author might make a very strong claim indeed on one ground which is not mentioned in the paper, namely, the great improvement in the atmosphere by a more extensive use of electrical power. Those who knew Tyneside 20 years ago, and who saw it after the group of electrical power companies had been at work there for several years, could not fail to notice the immense improvement in the atmosphere, and consequently in the conditions of living. If we can get the public well acquainted with the idea that the smoke and fogs with which we are so familiar in the West Riding can be largely done away with by the extension of electrical power, I think we shall have gone a long way towards getting them to accept some such proposals as the author suggests. It is time the public recognized that electrical power has become a national necessity and that private individuals—or perhaps I should say "the rights of private property"—cannot longer be allowed to stand in the way of its development. The author rightly points out that it will be necessary to get the approval of the Board of Trade to the proposals; this would be very valuable because it would to a great extent meet the objection that the facilities are wanted for private companies engaged in making dividends. The fact that they had to go to the Board of Trade would generally prevent supply companies from making unreasonable demands. This provision also meets another objection to the author's argument, that a definite consent must be given within one month. It seems rather hard sometimes to insist upon a definite reply within a month in the cases of small public bodies the members of which may live in scattered localities, and where the consent would have to be given by, say, the surveyor, or the surveyor in consultation with the clerk, or possibly the chairman. If, however, the companies showed any disposition to use that power arbitrarily or unreasonably the Board of Trade would be able to say that in certain cases a month's notice was really too short, and that it need not be adhered to. On the other hand the colliery companies also should learn that they must not run their machinery to the very last gasp and then expect an electrical authority 20 miles away to help them out within a month. I am particularly glad that the author proposes a tribunal upon which there should be no lawyers. Time and money would thereby be saved to a very considerable extent. The question whether an electrical power company should run mains across private land ought to be able to be settled [illegible]. The tribunal in fixing the amount to be paid for compensation would presumably consider any damage to the appearance of an estate, though that is not specifically mentioned. The knowledge that compulsory powers existed would make such [illegible]. It is too early to describe the effects of the recent Post Office Act [illegible] any legal cases. We have not yet had [illegible] that the new Act had been passed. They hesitated to go into Court and make public the terms that they had required for facilities which they thought were valuable to us but which really cost them nothing. I have no doubt a similar experience will be the lot of electrical power companies if similar powers are obtained. Mr. Johnson.

Mr. Brown **Mr. W. H. Brown**: The author refers on page 330 to the legal rights of a local authority in regard to the roads and the erection of wires over them; I should be glad if he would explain the position in regard to private suppliers. As I understand the matter, if a person owns property on both sides of a public road, or if one person desires to supply another on the opposite side of a road, it can rightly be done provided that the Board of Trade regulations are complied with, that the freehold of the land on which the road is made does not belong to the local authority, and that the supply is not run as the major portion of the business of the supplier. I understand that the instances in this country where the local authority owns the freehold of the roads are exceedingly few. How does the erection of tramway and telephone wires affect the private owners' rights, if they are as mentioned? The necessity and granting of wayleaves and consents is of much interest and importance to prospective consumers, and from conversations with landowners and factory proprietors in various parts of the country, I do not think it is yet realized how great the advantages are, and what benefits may be derived from a power line and supply. Could anything be done in the way of addressing Chambers of Commerce and similar institutions, in order to show the advantages arising from the granting of privileges in the direction required? From my own experience I am of the opinion that there is room for some missionary work, and I feel that if the matter could be plainly set out, there are many instances where a landowner would consider it his duty—even if he felt he was not sufficiently insisting on his rights—to allow cables to go across his property with a minimum of acknowledgment and an absence of irksome conditions. One thing which I think is at times in the mind of the landowner is, that whilst he may grant facilities for a power line, no portion of the profit which arises—or should arise—from the transaction finds its way into his pocket, the supply authority and the consumer sharing this between them—at least I hope so. If this point is of any moment, it emphasizes the need for a truly national power supply—possibly a modification of the telephone system. I do not think that the consumer troubles much as to the particular system or power house from which he is supplied; price and a constant voltage are usually the two things about which he concerns himself.

Mr. Lang. **Mr. W. Lang**: It seems to me that those who have had to deal with the cases described in the paper have been imbued with their own importance and with the importance of the necessity for electrical power supply instead of considering the question from the standpoint of the man who owns the rights of the land. Unless we divest ourselves of the feeling that such owners must give way, then I am certain we shall always have trouble in endeavouring to obtain wayleaves. If we take for instance the case on page [illegible] where a local authority was approached to grant wayleaves, whenever the question of the saving to the supply company was mentioned the

Mr. Lang.

interview was brought to a close. It appears to me that those who wish to obtain wayleaves must be instructed how to go about it. The paper certainly seems to show that the method of obtaining wayleaves has been rather haphazard. Apparently no very distinctive method has been adopted of educating those men how to obtain wayleaves. I believe it to be within the experience of all who have had this to do, that some men will be successful in a very great degree as compared with others. Now I do not think for a moment it is because they are abler men; it is simply because they are capable of dealing with the human element that they are up against. It is not a technical question at all, but simply one of dealing with ordinary human greed, shall I call it, or the desire to make the best of business. At the same time I think the necessity of obtaining compulsory powers has been forced upon the electrical industry. I am entirely in agreement with the tone of the paper. It is very fair indeed. The author does not look upon it from the standpoint that everybody should stand on one side or allow us to get wayleaves just as we have a mind to. He wants to be fair to the owner of the land. At the same time he wants that owner to be reasonable. The fact that the Post Office authorities only last year got further compulsory powers is to my mind a wonderful example of even a most powerful body having to seek such powers. And the way in which the Institution has now taken up this subject, and through Mr. Vernier has made it public to its members, I think will enhance the reputation of the Institution in the opinion of each member, because it will show them what an amount of interest the Institution is, as a body, taking in matters of vital interest to the industry.

Mr. Wallis.

Mr. E. C. **Wallis**: The point that impressed me first in connection with the paper was that all methods of civilization have had to meet with these same difficulties in making headway. We know that in the making of canals, railways, and various other methods of progress difficulties have been experienced which seemed almost insuperable. Nowhere are the rights of the private owner more considered than in the United Kingdom, but at the same time civilization cannot go forward if those rights are the sole consideration. That those rights should be absolute is unthinkable. On the other hand that there should be complete freedom of wayleave is also unthinkable. We must look forward to a mean between those extremes; because if unlimited leave were given we should have our country spoilt as some parts of Canada have been spoilt by the erection of overhead lines for power, lighting, etc. Compulsory powers under proper restrictions ought to be granted. The public convenience will be greatly restricted if that is not done. These new developments were not thought of 50 years ago. They have materialized and seem to be absolutely necessary for the progress of civilization, and there is no doubt that other developments will follow.

Mr. Vernier.

Mr. C. **Vernier** (*in reply*): Many of the points raised have already been considered in my previous replies,[*] to which I would refer contributors to this discussion. Mr. Woodhouse mentions the compulsory powers which have been conferred upon the Postmaster-General to enable him to run his wires on tramway standards. It may be of interest to add that the Postmaster-General has further the right to a perpetual (but not a free) wayleave over the whole system of a large number of railway companies whose public telegraph business was purchased by the State in 1868,[*] and also over the whole system of certain canal companies,[†] and can claim free wayleaves for his works over a number of other railways sanctioned in 1877 [‡] and over all undertakings sanctioned by Act of Parliament subsequent to the 1st January, 1878, of the following character, viz. railways, canals, tramways (but not street tramways), highways, bridges, railway and river embankments, subways, aqueducts over or across a river, dock, harbour, or pier.[§] He may also by agreement with the undertakers, lay telegraph cables in the trenches opened for the purpose of laying electric mains.[‖]

Mr. Verni

It is very pleasing to learn from Mr. Johnson, who confirms Sir William Slingo's and Mr. Stubbs' statements in the discussion before the Institution (page 346), that the Post Office have already experienced great benefit from the Act of 1916, and that so far there has been no need to resort to the Courts. It is further very encouraging to find that property owners who made unreasonable demands did not dare to make public the terms they demanded. It is well to point out, however, that the same publicity does not appertain to an arbitration as in a police or county court, which is the tribunal to whom the Post Office must carry its appeal in the first instance.

Mr. Brown refers to the position of non-statutory undertakers in the matter of the erection of wires across roads and streets. I have already dealt with this question at length in my reply to the discussion before the Institution, but there are other points upon which Mr. Brown would like information. The instances where the local authority owns the freehold of the roads, as he points out, are few, and these cases are mostly confined to roads that belonged to private turnpike authorities which were bought out by a local authority. In the case of other roads dedicated to public use, repairable by the inhabitants at large, the local authority, as a general rule, only has the right of user. In reply to the questions as to how tramway and telephone wires affect the owner's rights in the conditions mentioned, this will depend to some extent upon whether the owner's wires are erected before or after the other works. So long as the owner's wires are erected at a sufficient height so as not to interfere with the subsequent erection of tramway wires, i.e. with the ordinary user of the street or road, the owner's wires cannot be interfered with by the tramway authority. I am also of the opinion that the tramway authority would be liable for the cost of providing whatever guarding and protection is necessary because of the existence of the private owner's wires if these were erected first.

In the case of telephone wires erected under statutory powers, which in these days all come under the Postmaster-General, the great charter which brings all non-statutory undertakers or private owners within the mesh is Section 4 of the Electric Lighting Act 1888. This enables the Postmaster-General to serve a notice upon the private owner calling upon him to discontinue his supply if his works are injuriously affected thereby, and, secondly,

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[*] *Ante*, pages 355, 473, and 481.

[*] Telegraph Act 1868: Section 9 [6 (*h*)].

[†] *Ibid.*, Sections 11 and 12.

[‡] Telegraph Act 1878: Schedule.

[§] *Ibid.*, Section 6.

Telegraph Act 1892: Section 6.

[illegible] the Board of Trade to make an order upon the owner to the end that his wires shall only continue to be used in accordance with such regulations as the Board may prescribe, either generally or on behalf of the Postmaster-General or of some other person or authority. Until the private owner receives such a notice and assuming the absence of by-laws, he can do very much as he [illegible] at his own risk.

I quite agree with Mr. Lang that some men will be much more successful than others in securing wayleaves, but I think this is due in a greater measure to natural gifts than as the result of instruction. The art of negotiating wayleaves in the present conditions is not in the least comparable with an ordinary commercial transaction, and is more akin to that of the diplomat, without, however, the arbitrament of armed force in the last resort which gives power to his negotiations. In commerce, on the other hand, we have on one side a willing seller, on the other a willing purchaser, and as the arbiter competition, whereas in [illegible] negotiations we have usually an unwilling or at least an indifferent seller, a willing purchaser, but no competition or any other arbiter. Such negotiations are clearly not a business transaction in the usual sense of the term, and the demand for compulsory powers in effect amounts to a demand for arbitration to take the place of the usual competition. In this connection, it is worthy of notice that in other matters of public or social interest where competition is not available as a self-regulating form of control safeguarding such interests, the State finds it necessary to intervene and regulate such matters. It is, for example, owing to the absence of direct competition in [illegible] electricity, gas, water supply, etc., that the State regulates these undertakings, for although they are subject to some competition by other forms of [illegible], yet in their own sphere they are each [illegible].

As there is a general lack of information on the part of the public, and even on the part of electricity supply engineers who are not closely concerned with management, [illegible] profits or receive any more than a reasonable return on their capital. In the case of a company working under a Provisional Order, maximum charges are scheduled in [illegible] be revised by the Board of Trade every 5 years on the [illegible] prove a very profitable one, there [illegible] itself of its power to purchase the undertaking at the first opportunity. Mr. Vernier.

In the case of power companies, the dividends are usually restricted to 8 per cent, and can only be increased above this figure according to a prescribed scale, provided that the average price charged for electrical energy falls below the scheduled scale of maximum charges. This dividend scale, and also the scale of maximum charges, is subject to revision by the Board of Trade every 5 years on the application of the company, of three authorized undertakers, or of twenty or more consumers, but in this case there is no right of purchase by local authorities. When we have companies of this character under the close control of the public, and by the State, it is not unreasonable to ask that they should have equal facilities to a State undertaking, for this reason, that the public interest demands that the service should be given in the best and freest possible manner, and at a minimum of cost. If the public interest suffers because the company is looked upon as exploiting the public for its own benefit, then it is fundamentally wrong to put such service into the hands of a company. This, however, is not the view of Parliament, which recognizes the advantages which accrue to the community from the element of self interest in private enterprise, even when so controlled and limited, and to which our electricity supply industry owes so much. Yet Parliament only too often reflects the public's distrust of its power to exercise proper control by withholding facilities from company undertakings which it would readily grant to a State or even to a municipal undertaking.

The suggestion that this leads up to a national scheme of electricity supply, meaning thereby an entirely State-owned and managed undertaking, is one that will inevitably present itself to many. I myself think that so far as generation and transmission in bulk is concerned, we may see it come to pass. But the electricity supply industry in its present stage of evolution is not one which many consider could be taken over by the State with any advantage to the national interest. An industry which in the course of unprecedented invention and progress has found it necessary to discard and renew its generating plant at least twice within the last 15 years, which in the same period has developed new problems of transmission applicable to the special conditions in this country, and which at the present time foresees important experimental developments in high-voltage cables and transmission, coal carbonization, and recovery of by-products, etc., is not one which can be said to be ripe for the conservatism of State ownership and management. The proposals outlined last year by Mr. E. T. Williams,* which while preserving freedom of enter[illegible], were directed to the [illegible] industry on a national [illegible]-supply undertaking on the [illegible].

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* [illegible]

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THE MATHEMATICAL TREATMENT OF THE MAGNETOMOTIVE FORCE OF ARMATURE WINDINGS.*

By B. HAGUE, B.Sc.

(*Paper first received 8 March, and in final form 29 May, 1917.*)

SUMMARY.

The paper aims at giving a complete analytical treatment of the magnetomotive force produced by a polyphase armature winding. The fundamental principles and the scope of the investigation are enunciated in Section 1. In Section 2 the magnetomotive force of a winding composed of full-pitch coils carrying sinusoidal phase-currents is investigated, and the results are applied to the case of a uniformly distributed winding in Section 3, and to a slotted armature in Section 4.

The effect of the coil-span on the distribution of magnetomotive force is discussed in Section 5, and a complete generalization of all the foregoing results for currents of any wave-form is given in Section 6.

SYNOPSIS.

1. *General introduction and fundamental ideas.*
    - (*a*) Graphical method.
    - (*b*) Analytical method.

2. *The magnetomotive force distribution due to an armature winding with full-pitch coils carrying polyphase sinusoidal currents.*
    - I. Deduction of the equation to the M.M.F. wave.
        - (*a*) Properties of moving waves.
    - II. Simplification of equation to M.M.F. wave for symmetrical polyphase systems, $\beta = 2\pi/N$.
        - (*a*) The harmonics present in the M.M.F. wave.
        - (*b*) The harmonics absent from the M.M.F. wave.
    - III. Simplification of equation to M.M.F. wave for hemisymmetrical polyphase systems, $\beta = \pi/N$.
        - (*a*) The harmonics present in the M.M.F. wave.
        - (*b*) The harmonics absent from the M.M.F. wave.

3. *Determination of the equation to the M.M.F. wave due to a uniformly distributed winding with full-pitch coils carrying polyphase sinusoidal currents.*
    - (*a*) Determination of b_n for a single uniformly distributed phase.
    - I. Single-layer windings.
        - (*a*) Single-phase windings with various phase-spreads.
        - (*b*) Hemisymmetrical two-phase winding.
        - (*c*) Symmetrical three-phase winding.
    - II. Closed double-layer windings.
        - (*a*) Two tappings, π radians apart.
        - (*b*) Four " , $\pi/2$ " "
        - (*c*) Three " , $2\pi/3$ " "
        - (*d*) Six " , $\pi/3$ " "
    - III. Opened double-layer windings.
        - (*a*) Hemisymmetrical two-phase winding.
        - (*b*) Symmetrical three-phase winding.
    - IV. Discussion of results.
        - (*a*) Amplitude of the fundamental and maximum height of limiting forms of the wave of magnetomotive force.
        - (*b*) Direction of motion and speed of harmonics.
        - (*c*) Theory of the periodic change of shape of the M.M.F. wave.

4. *The effect of the concentration of the coils in slotted armatures upon the shape of the M.M.F. wave due to sinusoidal phase-currents* (*full-pitch coils*).
    - I. Single-layer windings with full-pitch coils.
    - II. Double-layer windings with full-pitch coils.
    - III. Illustrative example.
        - Three-phase single-layer winding with 3 slots per pole and phase.

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* The present paper constitutes part of an extensive investigation into the properties of armature windings which has been carried out in the Post-Graduate Courses at the City and Guilds (Engineering) College in the Department of Electrical Engineering under the direction of Dr. S. P. Smith. The work was commenced by the author in the session 1915–16 in order to supersede the graphical method of studying the problem of the M.M.F. of a winding by a purely analytical process. It was the object of the author to generalize certain results relating to three-phase windings given by Dr. Smith and Mr. W. H. Barling (*Electrician*, 1914, vol. 74, p. 43), and to extend the analytical treatment given in the treatises of Arnold and Russell.

The first and second parts of the investigation referred to have formed the subjects of two papers already published (S. P. SMITH: *Journal I.E.E.*, 1917, vol. 55, p. 18; and B. HAGUE: *Electrician*, 1917, vol. 78, p. 710), and the present communication forms the third part and should be read in conjunction with them, since it is largely based on the results arrived at therein.

5. *The effect of the high harmonics on the shape of the M.M.F. wave of a polyphase winding carrying sinusoidal currents.*

8. The determination of the additional harmonics introduced into the equation to the wave of magnetomotive force by the process of altering the coil span.
   - (a) Simplification for balanced polyphase systems, [illegible]
   - (b) Simplification for unsymmetrical polyphase systems, [illegible]

9. Determination of c_n and ζ for uniformly distributed windings.

10. Determination of c_n and ζ for a winding in which the coils are concentrated in slots.

11. Illustrative examples of the effect of altering the coil span.

6. *The effect of non-sinusoidal currents on the shape of the M.M.F. wave.*

Conclusion.

LIST OF SYMBOLS.

$B_n =$ [illegible]
$B_n' =$ [illegible]
$C =$ [illegible]
$\Gamma =$ instantaneous value of the M.M.F. at any place due to the fundamental current.
$\Gamma_{n'} =$ instantaneous value of the M.M.F. at any place due to the n'th harmonic in the current.
$\Gamma_{max} =$ amplitude of the phase M.M.F. produced by fundamental current.
$\Gamma_{n', max} =$ amplitude of the phase M.M.F. produced by the n'th harmonic in the current.
$I =$ the root-mean-square value of the phase-current.
$K =$ [illegible]
$N =$ number of phases.
$Q =$ number of slots per pole.
$T =$ period of fundamental current $= 1/f$.
$T_{n'} =$ period of n'th current harmonic $= 1/f_{n'}$.
$T_c =$ turns per coil.
$Y =$ pole-pitch in cm.

$a =$ constant term in Fourier series for harmonics due to short coil-span.
$a_n =$ cosine coefficient in Fourier series for harmonics due to short coil-span.
$b_n =$ sine coefficient in Fourier series for harmonics due to short coil-span.
$b_n =$ sine coefficient in Fourier series for a wave of phase M.M.F. of unit amplitude due to full-pitch coils.
$c_n^2 = a_n^2 + b_n^2$.
$f =$ fundamental frequency.
$f_{n'} =$ frequency of n'th current harmonic.
$k_n =$ distribution factor of the nth harmonic for q coils

$$= \frac{\sin (q n \gamma / 2)}{q \sin (n \gamma / 2)}$$

$k_n' =$ coil-span factor of the nth harmonic [illegible]
$i_m =$ instantaneous value of current in the mth phase.
$i_{n'} =$ maximum value of n'th harmonic in phase current wave.
$k =$ a positive integer inclusive of zero.
$m =$ the number of a phase in general equations = any integer.

$n =$ order of space harmonic in the M.M.F. wave.
$n' =$ order of harmonic in phase current wave.
$p =$ a positive integer > 0.
$q =$ slots per pole and phase $= Q/N$.
$q_w =$ wound slots per pole and phase.
$r =$ a positive integer inclusive of zero.
$t =$ time.
$u =$ coil-sides per slot in a double-layer winding.
$u =$ conductors per slot in a single-layer winding.
$v_n =$ linear speed of nth M.M.F. harmonic around the armature periphery.
$x =$ space co-ordinate measured in cm. round the armature periphery $= Y\theta/\pi$.
$z =$ number of conductors per pole-pitch.
$\alpha =$ phase displacement between currents in successive phases.
$\beta =$ angular phase-pitch.
$\gamma =$ angular slot-pitch.
$\epsilon =$ angular deviation of coil-span from a full pitch of π radians.
$\zeta =$ fraction of a pole-pitch moved by the fundamental of the M.M.F. wave before any given wave-shape is repeated.
$\zeta_n = \tan^{-1}$ [illegible]
$\theta =$ a space angle measured in radians.
$\chi =$ the width of a slot at the armature periphery, measured in radians.
$\sigma =$ angular phase-spread.
$\phi_{n'} =$ epoch of the n'th current harmonic.
$\omega = 2 \pi f$.
$\omega_{n'} = 2 \pi f_{n'} = \omega n'$.

1. GENERAL INTRODUCTION AND FUNDAMENTAL IDEAS.

In dealing with the theory of alternating-current machinery, the distribution of the magnetic field in the air-gap must be determined, in order that such problems as the determination of the shape of the pressure wave in an alternator or the wave-form of the magnetizing current taken by an induction motor, may be accurately solved. It is the custom in an analytical treatment of such problems to express the shape of the magnetic field wave-form in a Fourier's series of sines and cosines of a space angle, and to deal with the effect of each term of such a series on the phenomenon under consideration. In such a simple case as that of an alternator on open circuit the magnetic field is produced entirely by the difference of magnetic potential between the field system—having salient or non-salient poles, as the case may be—and the surface of the armature core, and, under the assumption that the air-gap has a constant reluctance everywhere, the curve representing the distribution of flux density around the periphery of the machine will have the same shape as that giving the magnetomotive force acting at every point across the gap. Under such conditions the equations for the flux-density distributions can be readily worked out, and many are to be found in Dr. S. P. Smith and Mr. Boulding's paper * on the shape of the pressure wave of an alternator on no load.

When, however, we turn to the case of an alternator on load or on short-circuit,† the magnetic field is produced by the resultant at every point of the magnetomotive forces of the field system and the currents in the armature winding. Furthermore, if the case of an induction motor on no load be considered, the field is produced by the M.M.F. of the stator winding; while on any state of load the resultant M.M.F. of the stator and rotor currents is responsible for the magnetic field.

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* S. P. Smith and R. S. H. Boulding, Journal I.E.E., [illegible]

† A. B. [illegible]

Thus, it appears that the determination of the M.M.F. due to an armature winding carrying polyphase currents must be made before the space distribution of the magnetic field in the air-gap of an electrical machine can be properly calculated. In the present paper an attempt is made to set out in some detail the method of finding the peripheral distribution of the M.M.F. due to the current-carrying coils of any type of polyphase winding. It is intended in a future paper to show how the armature M.M.F. can be superposed on the M.M.F. of the field system of an alternator, and in the case of an induction motor* to point out how the resultant of the stator and rotor M.M.F. can be obtained. Thence, for any state of load, the shape of the curve of field distribution can be found, and the author hopes to show how the effect of non-uniform gap reluctance and the action of hysteresis and saturation in the magnetic circuit on the shape of the field can be determined. The present paper is, however, strictly confined to the treatment of the magnetomotive force of a polyphase winding by mathematical methods.

The magnetomotive force distribution due to an armature winding has been treated mathematically by Dr. Russell † and E. Arnold ‡ independently, and the methods to be followed in this paper are substantially similar to those used by Dr. Russell. The results obtained are, however, of greater generality, and therefore applicable to a larger variety of cases.

There are two methods of finding the distribution of magnetomotive force due to an armature winding, which we can call the "Graphical" and the "Analytical" methods respectively. The graphical method is simple and quick, and has been employed throughout this paper in making the diagrams, since it gives the shape of the wave of M.M.F. at once and avoids the plotting of a Fourier's series. Plotting the wave from its analytical series is a laborious process and as a rule is of the nature of an approximation only, unless the series be so rapidly convergent that only a few terms are needed to give a close approach to the actual shape. However, in exact theory the mathematical expressions for the quantities under consideration are a necessity, and the present paper is largely devoted to the derivation and discussion of the series which represents the wave of magnetomotive force.

(*a*) *Graphical method.*—Consider a polyphase winding whose phases are carrying currents of known wave-form, and let it be required to find the distribution of magnetomotive force at an instant t. From a wave or a polar diagram the currents in the conductors of every phase are known in value and direction. Let a diagram be drawn showing the peripheral distribution of the armature conductors, and for the present let the conductors belonging to one phase be considered alone. The magnitude and direction of the current in the conductors of this phase being known, let a curve be plotted whose abscissæ are centimetres measured around the periphery and whose ordinates represent to some scale the number of ampere-conductors per cm. at each point. Let such a curve be drawn for every phase in the armature, the graphical summation of all the curves giving what may be termed the peripheral loading curve for the instant in question. If y denotes the ordinates of this curve at x cm. from a chosen origin, we can write $y=f(x)$ as the instantaneous equation to the loading curve. The total magnetomotive force at x is, by elementary principles, given by $4\pi\int_0^x f(x)\,dx$. Now we shall readily see that the peripheral loading curve consists of parts of straight lines parallel to the axis of x, and so this integration can be carried out with ease by means of the customary graphical methods. Obviously the whole construction must be repeated for every instant of time at which the wave of M.M.F. distribution is required.

(*b*) *Analytical method.*—Although of great practical use, it is clear that very little of the properties of the M.M.F. wave could be inferred from the graphical process, and hence it is necessary in exact theory to seek for analytical methods of procedure.

It will be obvious that each phase of a winding will produce a magnetomotive force represented by the Fourier series $\psi(x)$ whose value will pulsate according to the law of variation of the current in the conductors of the phase. If $f(t)$ represent the current in the phase considered—f being the Fourier series for the current wave-form—it is clear that the M.M.F. of the phase is proportional to $f(t)\cdot\psi(x)$. Hence, in general, the analytical equation to the shape of the M.M.F. wave of the whole winding will be given by

$$\sum_{m=1}^{m=N} f_m(t)\cdot\psi_m(x),$$

where f_m. ψ_m, are the forms of the functions for the mth phase, the summation extending over the total number of phases, N. The evaluation of this product of Fourier series is readily carried out with the aid of the usual summation theorems for sine and cosine series, and it will be our object to develop this general equation in the subsequent sections of this paper.

2. The Magnetomotive Force Distribution due to an Armature Winding with Full-pitch Coils carrying Polyphase Sinusoidal Currents.

In this section we shall deduce the general equations giving at any instant of time the distribution of magnetomotive force due to any type of polyphase armature winding with full-pitch coils, the only assumption being that the currents carried thereby are of sinusoidal waveform. The problem can be considered under the following headings :—

I. *Deduction of the equation to the M.M.F. wave.*—Each individual phase of an armature winding supplied with a sine current produces a magnetomotive force which is stationary in space with respect to the winding and pulsates, or varies as a sine function of the time, the instantaneous contour of the M.M.F. depending entirely on the distribution around the armature periphery of the conductors forming the phase under consideration. The sum of the pulsating M.M.F. waves of the individual phases is the M.M.F. of the winding as a whole, and in general this resultant magnetomotive force is a wave moving around the periphery of the armature at synchronous speed, the shape of the wave changing cyclically during [illegible], as we shall presently see.

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* A paper on the "Air-gap Field of an Induction Motor," by Dr. F. T. Chapman, was published (*Electrician*, 1916, vol. 77, p. 663) whilst the present paper was in preparation.

† A. Russell: "Alternating Currents," vol. 2, 2nd edition, pp. 422–435.

‡ E. Arnold: "Die Wechselstromtechnik," 1904, vol. 3, chap. 13, p. 294. See also H. Weichsel, *Transactions of the American Institute of Electrical Engineers*, 1915, vol. 34, p. 2721; and M. B. Field, *Electrical Review*, 1899, vol. 44, p. 194.

Now the space distribution of the magnetomotive forces of the individual phases can be readily expressed in a Fourier series of sines and cosines of θ, where θ is a space angle measured from a chosen origin on the periphery to any point. In this series the amplitudes of the harmonics are functions of the time and follow the same harmonic law as the currents. Let us take the currents as varying according to a cosine law, the phase displacement between the currents in successive phases being α. Further, let the phases be displaced from each other around the armature circumference by an angular phase-pitch β. Then, we can write for the currents:—

$$i_{I} = i \cos \omega t, \text{ in the first phase,}$$
$$i_{II} = i \cos (\omega t - \alpha), \text{ in the second phase,}$$
$$i_{III} = i \cos (\omega t - 2\alpha), \text{ in the third phase,}$$

. . . .

and in general $i_m = i \cos [\omega t - (m-1)\alpha]$, in the mth phase.

where i is the maximum value attained by the currents in turn, and $\omega = 2\pi f$, f being the frequency of the current.

In Fig. 1 the [illegible] waves of phase M.M.F. of an N-phase [illegible] are shown, and for sake of generality [illegible] are assumed. It will be shown later that the phase M.M.F. of a uniformly distributed winding must be represented by a trapezoidal wave, which in certain special cases reduces to one of the limiting forms of a [illegible] or rectangular wave; whereas in the case of a [illegible] the phase M.M.F. is represented by a stepped wave composed of the sum of a number of [illegible] one for each coil of the phase. Whatever form the wave of phase M.M.F. may assume, much simplification can be secured in expressing the wave shapes in a Fourier series, by taking the origin at the place where the magnetomotive force of the first phase is zero; that is to say, we shall always take the origin at the middle of the phase band of Phase I. The series will then contain only odd sine terms, owing to the symmetry of the wave about the $\pi/2$ ordinate, and cosine terms will be entirely absent. Then we shall have the following expressions for the waves of magnetomotive force distribution of the individual phases:—

$$F_{I} = F_{max} \cos \omega t \, [b_1 \sin \theta + b_3 \sin 3\theta + \dots b_n \sin n\theta + \dots]$$

$$F_{II} = F_{max} \cos (\omega t - \alpha) \, [b_1 \sin (\theta - \beta) + b_3 \sin 3 (\theta - \beta) + \dots b_n \sin n (\theta - \beta) + \dots]$$

$$F_{III} = F_{max} \cos (\omega t - 2\alpha) \, [b_1 \sin (\theta - 2\beta) + b_3 \sin 3 (\theta - 2\beta) + \dots b_n \sin n (\theta - 2\beta) + \dots]$$

and so on; so that in general for the mth phase,

$$F_m = F_{max} \cos [\omega t - (m-1)\alpha] \, \{b_1 \sin [\theta - (m-1)\beta] + b_3 \sin 3 [\theta - (m-1)\beta] + \dots b_n \sin n [\theta - (m-1)\beta] \dots\}$$

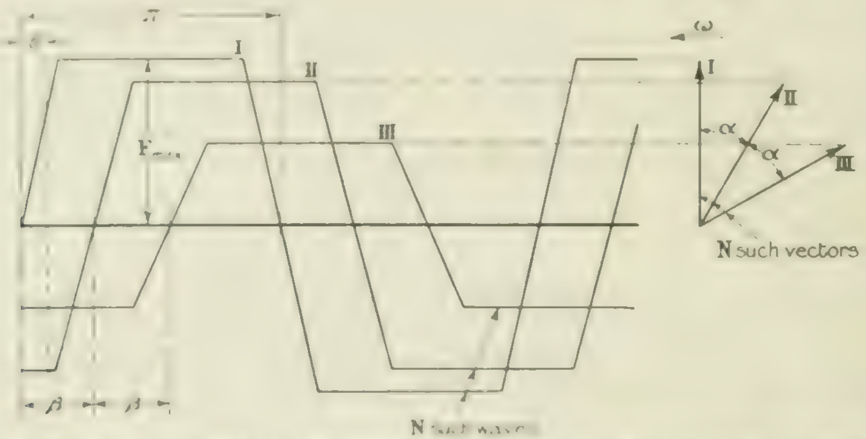

Fig. 1.—Showing M.M.F. waves produced by the phases of an N-phase uniformly distributed winding with full-pitch coils

Hence the resultant M.M.F. of the whole winding at a point on the periphery subtending an angle θ from the origin at the instant of time t, is the sum of these expressions for the total of N phases, i.e.

$$F = F_{max} \sum_{m=1}^{m=N} \left\{ \cos [\omega t - (m-1)\alpha] \left[\sum b_n \sin n [\theta - (m-1)\beta] \right] \right\} \quad (1)$$

In this equation F_{max} is the amplitude of the M.M.F. of a phase; n is the order of the M.M.F. space-harmonic and is an odd integer. The quantity b_n is the coefficient of the nth harmonic in the Fourier expansion of a wave of phase M.M.F. having unit amplitude. The inner summation—within the [ ] shaped bracket—is the usual abbreviated form for the Fourier series and embraces odd values only.

It is convenient to study the effect of the nth space harmonic in the phase M.M.F. on the resultant M.M.F. of the winding. By this means we can examine each harmonic in turn and obtain summations which are easy to perform. Thus the *n*th harmonic in the resultant M.M.F. is given by

$$F_n = \bar{F}_{\max} b_n \sum_{m=1}^{m=N} \cos[\omega t - (m-1)\alpha] \sin n[\theta - (m-1)\beta]$$

$$= B_n \sum_{m=1}^{m=N} \tfrac{1}{2}\Big[\sin\{n\theta + \omega t - (m-1)(n\beta + \alpha)\}$$

$$+ \sin\{n\theta - \omega t - (m-1)(n\beta - \alpha\}\Big],$$

where $B_n = \bar{F}_{\max} b_n$.

Summing the series in the usual way we get

$$F_n = \frac{B_n}{2}\Big[\sin\{n\theta + \omega t - \tfrac{1}{2}(N-1)(n\beta+\alpha)\}\frac{\sin\frac{1}{2}N(n\beta+\alpha)}{\sin\frac{1}{2}(n\beta+\alpha)}$$

$$+ \sin\{n\theta - \omega t - \tfrac{1}{2}(N-1)(n\beta-\alpha)\}\frac{\sin\frac{1}{2}N(n\beta-\alpha)}{\sin\frac{1}{2}(n\beta-\alpha)}\Big] \quad (2)$$

These general equations, (1) and (2), can be somewhat simplified in order to deal with practical cases. In all practical polyphase armatures the time angle of phase difference, α, between the currents in successive phases is the same as the angular phase-pitch, β, by which the phases are separated from each other around the armature periphery. Thus, inserting $\alpha = \beta$, we have

$$F_n = \frac{B_n}{2}\Big[\sin\{n\theta + \omega t - \tfrac{1}{2}(N-1)(n+1)\beta\}\frac{\sin\frac{1}{2}N(n+1)\beta}{\sin\frac{1}{2}(n+1)\beta}$$

$$+ \sin\{n\theta - \omega t - \tfrac{1}{2}(N-1)(n-1)\beta\}\frac{\sin\frac{1}{2}N(n-1)\beta}{\sin\frac{1}{2}(n-1)\beta}\Big] \quad (3)$$

and

$$F = \sum_{n=1}^{n=\infty} F_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

as the general equations to the *n*th space harmonic in the M.M.F. wave and the entire M.M.F. wave of the winding respectively.

(*a*) *Properties of moving waves.*—If a certain state represented by the equation $y = a \sin n(\theta + \phi_n)$ be moving with a constant linear velocity v_n around the circumference of a circle, the value of y at any instant t will be $y = a \sin n(\theta + \phi_n \mp \omega_n t)$, where ω_n is the angular velocity corresponding to v_n. The negative sign occurs when the motion is in the positive direction of θ, namely, counter-clockwise. Such a wave is known variously as a "*moving*," "*rotating*," or "*gliding*" wave of constant type.

Let the circle around which such a wave is moving be the periphery of our armature, and let 2 Y denote the fundamental wave-length (or double pole-pitch) measured in cm. Then, since $\theta/\pi = x/Y$, where x is the distance around the periphery subtending the angle θ, we can write $y = a \sin n(\pi x/Y + \phi_n \mp \omega_n t)$. Since the wave is progressive it follows that it will be of constant type if $\pi x/Y \mp \omega_n t$ is constant, i.e. if $v_n = dx/dt = \pm \omega_n Y/\pi$. But the linear velocity of a wave is its wave-length divided by its period. The wave-length of the *n*th harmonic being $2Y/n$ and its period $T = 1/f = 2\pi/\omega$, we easily get $v_n = (2Y/n)[\omega/(2\pi)] = \omega Y/(n\pi)$. Equating the two values of v_n gives $\omega_n = \omega/n$, and so we can write

$$y = a \sin(n\theta \mp \omega t + \phi'_n),$$

as the equation to a moving wave of constant type. Comparing this with Equations (3) and (4) the following conclusion is arrived at :—

The M.M.F. of an armature winding consists of the sum of a number of moving waves of constant type, the *n*th harmonic wave progressing around the armature periphery at 1/*n*th of the speed of the fundamental wave, i.e. at 1/*n*th of synchronous speed.

Equation (3) also shows that some waves move in the opposite direction to others ; those having the negative sign before ω moving counter-clockwise and those with the positive sign progressing clockwise, θ being taken positive in a counter-clockwise direction, as is usual in angular measurement.

It is well known that the sum of a number of sine waves of various wave-lengths moving at devious velocities is a wave of changing shape moving at an irregular speed. Hence, the wave of magnetomotive force due to a polyphase armature winding carrying sinusoidal currents, moves around the armature periphery at an irregular speed, and changes its shape in a cyclic manner during the motion.

These points will be reconsidered in greater detail when we come to deal with concrete cases in Section 3.

II. *Simplification of equation to M.M.F. wave for symmetrical polyphase systems,* $\beta = 2\pi/N$.—By a consideration of the values assumed in practice by β, Equation (3) can be still further simplified. Steinmetz * has shown that there are two chief classes of polyphase systems of currents used in practice ; namely, the symmetrical system in which $\beta = 2\pi/N$, and the hemisymmetrical in which $\beta = \pi/N$. We must therefore show how these definitions simplify our present problem, dealing first with the case of $\beta = 2\pi/N$.

(*a*) *The harmonics present in the M.M.F. wave.*—Inserting $\beta = 2\pi/N$ in Equation (3) several cases arise, dependent on the relation between n and N. Now since

$$\tfrac{1}{2}N(n \pm 1)2\pi/N = (n \pm 1)\pi,$$

$$\sin\tfrac{1}{2}N(n \pm 1)\beta = \sin(n \pm 1)\pi = 0,$$

and so in general $F_n = 0$. However, if

$$(n + 1)\beta/2 = \tfrac{1}{2}(n + 1)2\pi/N$$

be an integral multiple of π or 2π, the denominator of the first term vanishes, leaving the first term of the form 0/0, the limiting value of which is N ; the second term still remains zero. Likewise the first term will vanish and the second assume the same limiting form if

$$(n - 1)\beta/2 = \tfrac{1}{2}(n - 1)2\pi/N$$

be an integral multiple of π or 2π. Remembering that n is an odd integer and can be written as $n = 2r + 1$, where r is any positive integer (inclusive of zero), we get results which may be summarized as follows :—

(*a*) If both r and $r + 1$ are not multiples of N :—

$$F_n = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5a)$$

(*b*) If $r + 1 = kN$, i.e. $n = 2kN - 1$, and N is odd or even :—

$$F_n = \tfrac{1}{2}NB_n \sin(n\theta + \omega t) \quad . \quad . \quad . \quad . \quad (5b)$$

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* C. P. STEINMETZ : "Theory and Calculation of Alternating-current Phenomena," 4th edition, pp. 634–642.

(c) If $r = kN$, i.e. $n = 2kN + 1$ and N is odd or even —

$$F_n = \frac{1}{2} N B_n \sin(n\theta - \alpha t) \quad . \quad . \quad . \quad (5c)$$

(d) If $r + 1 = \frac{1}{2} kN$, i.e. $n = kN - 1$, and N is even —

$$F_n = -(-1)^{[illegible]} \frac{1}{2} N B_n \sin(n\theta + \alpha t) \quad . \quad . \quad (5d)$$

(e) If $r = \frac{1}{2} kN$, i.e. $n = kN + 1$, and N is even —

$$F_n = -(-1)^{[illegible]} \frac{1}{2} N B_n \sin(n\theta - \alpha t) \quad . \quad (5e)$$

The quantity k is any positive integer, inclusive of zero.

Hence the harmonics present in the M.M.F. wave of an N-phase symmetrical armature winding are those of order $2kN \pm 1$ when N is odd together with those of order $kN \pm 1$ when N is even. All the existent harmonics are moving waves of sine shape, progressing round the armature periphery at speeds inversely proportional to their respective orders, the direction of motion of harmonics of orders $kN + 1$ and $2kN + 1$ being counter-clockwise (θ positive), whilst the $kN - 1$ and $2kN - 1$ harmonics move in the reverse sense.

(b) *The harmonics absent from the M.M.F. wave.*—It will be seen from Equations (5b) to (5e) inclusive that the M.M.F. harmonics present are those whose orders are not multiples of N. Hence it follows that the harmonics absent from the M.M.F. wave of an N-phase symmetrical armature winding are those whose orders are odd multiples of N (when N is odd), or odd multiples of N/2 (when N is even and N/2 odd). These are the harmonics for which r and $r + 1$ are not multiples of N, and hence their absence follows at once from Equation (5a).

III. *[illegible] of [illegible] to M.M.F. wave for hemisymmetrical polyphase systems* $\beta = \pi/N$.—Dealing now with the second of Steinmetz's two cases, put $\beta = \pi/N$ in Equation (3) and the following results are obtained :—

(a) *The harmonics present in the M.M.F. wave in this case.*—We shall now have

$$\frac{1}{2} N (n + 1) \beta = \frac{1}{2} N (n + 1) \pi / N = (n + 1) \pi / 2$$

and remembering that n is odd and therefore $n + 1$ is even, we get, $\sin \frac{1}{2} N (n + 1) \beta = \sin$ (integral number of times π) $= 0$, and so in general $F_n = 0$.

As before, we shall find that for certain values of n, one or other of the two terms forming Equation (3) assumes the indeterminate form whose limit is N, the remaining term vanishing. Using our previous notation it is easy to prove the results set out in the following summary :—

(a) If both r and $r + 1$ are not multiples of N :—

$$F_n = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6a)$$

(b) If $r + 1 = kN$, i.e. $n = 2kN - 1$, and N is odd or even :—

$$F_n = -(-1)^{[illegible]} \frac{1}{2} N B_n \sin(n\theta + \alpha t) \quad (6b)$$

(c) If $r = kN$, i.e. $n = 2kN + 1$, and N is odd or even :—

$$F_n = (-1)^{[illegible]} \frac{1}{2} N B_n \sin(n\theta - \alpha t) \quad (6c)$$

Hence the harmonics present in the M.M.F. wave of an N-phase hemisymmetrical armature winding are those of order $2kN \pm 1$ when N is odd or even. All the existent harmonics are moving waves of sine shape, progressing round the armature periphery at speeds inversely proportional to their respective orders, the direction of motion of harmonics of order $2kN + 1$ being counter-clockwise (θ positive), whilst the $2kN - 1$ harmonics move in the reverse sense.

In practice the only hemisymmetrical polyphase system in general use is the two-phase (or as called in America, the "quarter-phase") system, and we shall confine our subsequent work on hemisymmetrical windings to the case of the two-phase arrangement alone.

(b) *The harmonics absent from the M.M.F. wave in this case.*—As before, our equations show that the M.M.F. harmonics present are those whose orders are not multiples of N. Hence, we can say that the harmonics absent from the M.M.F. wave of an N-phase hemisymmetrical armature winding are those whose orders are odd multiples of N (when N is odd), or odd multiples of N/2 (when N is even and N/2 odd).

This statement and the one given in Section II (a) of the present part of the paper do not apply when $N = 1$ or 2, as the following formal proof will show.

(a) *N an odd integer.*—Since we have to prove that a harmonic whose order is an odd multiple of N vanishes from the M.M.F. wave, write $n = 2r + 1 = (2p - 1) N$, where p is a positive integer > 0. Then we shall have $r = \frac{1}{2}[(2p - 1) N - 1]$ and $r + 1 = \frac{1}{2}[(2p - 1) N + 1]$, which unless N is 1 are neither integral multiples of N. Hence, with this exception, Equations (5a) and (6a) show that the harmonics corresponding to these values of r are zero.

(b) *N/2 an odd integer.*—As before, put

$$n = 2r + 1 = (2p - 1) N / 2,$$

giving $r = \frac{1}{4}[(2p - 1) N - 2]$ and $r + 1 = \frac{1}{4}[(2p - 1) N + 2]$, which, unless $N = 2$, are neither integral multiples of N. Hence, with this exception, the harmonics corresponding thereto vanish, as Equations (5a) and (6a) show.

3. DETERMINATION OF THE EQUATION TO THE M.M.F. WAVE DUE TO A UNIFORMLY DISTRIBUTED WINDING WITH FULL-PITCH COILS CARRYING POLYPHASE SINUSOIDAL CURRENTS.

We have shown in the previous section how the equation to the M.M.F. wave due to any type of armature winding carrying sinusoidal currents can be determined, and have expressed the magnitude of each harmonic in the wave in terms of a quantity, $B_n = \overline{F}_{max} b_n$. Now $\overline{F}_{max}$ is the maximum magnetomotive force per pole and phase, and therefore depends entirely on the number of conductors per phase and on the amplitude of the phase current; b_n, on the other hand, is entirely dependent on the manner in which the armature conductors are distributed around the periphery. It will therefore be apparent that the distribution of the armature conductors must be decided upon before b_n can be determined and the results for the M.M.F. equation written down.

In the elementary theory of electrical machinery it is common practice to neglect the effects of the armature slots and teeth,* and so in this section we shall assume that the armature consists of a smooth circular cylinder upon the surface of which the conductors forming the winding are arranged. These conductors are to be uniformly dispersed around the periphery, and are to be strictly contiguous, i.e. no space is to be lost by insulation or by any armature teeth. The whole circumference will thus be occupied by active conductors, and such a winding representing the simplest arrangement which can be considered, will be called a "uniformly distributed winding." The phases of the winding will thus consist of contiguous current sheets arranged on the periphery at the appropriate phase-pitch apart. In Section 4 we shall show how the simple results arrived at under the present assumptions need to be modified when the conductors are concentrated in similar bunches in equidistant slots separated by teeth. Furthermore, as pointed out in the beginning of Section 2, we shall assume that the coils constituting the winding have a span of a full-pitch, leaving the consideration of other coil-spans until Section 5.

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* [illegible]

Under these conditions we can turn to the consideration of the value of b_n, and thence proceed to the M.M.F. equation for single-layer or for double-layer open and closed windings with various numbers of phases.

(*a*) *Determination of b_n for a single uniformly distributed phase.*—A phase of a uniformly distributed winding supplied with a sine current will give rise to a magnetomotive force which is stationary with respect to the winding, and which pulsates as a sine function of time. The space distribution of the pulsating M.M.F. of a phase will have one of the forms of a rectangular, trapezoidal, or triangular wave according as the winding forming the phase is concentrated, partially distributed over the pole-pitch, or wholly distributed over it. Such magnetomotive force waves are shown in Figs. 2 (*a*), (*b*), (*c*), together with the current sheets producing them. The waves are assumed to be of unit amplitude, so that b_n is readily found by Fourier analysis.

Taking the trapezium as the general case, Fig. 2 (*b*), it is easy to prove that

$$b_n = \frac{8}{\pi n^2 \sigma} \sin n \frac{\sigma}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where n is odd and σ is the angular phase-spread of the current sheet formed by the coil-sides of the phases.

The triangle, Fig. 2 (*c*), is easily found by putting $\sigma = \pi$ in Equation (7) giving

$$b_n = \frac{8}{\pi^2 n^2}(-1)^{\frac{1}{2}n-\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (8)$$

In a similar way, by putting $\sigma = 0$ and using the method of limits, we get for the rectangle of Fig. 2 (*a*)

$$b_n = \frac{4}{\pi n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Values of b_n for the various values of σ arising in practice are given in Table 1.

TABLE 1.

σ	b_1	b_3	b_5	b_7	b_9	b_{11}	b_{13}	b_n
0	$4/\pi$	$4/3\pi$	$4/5\pi$	$4/7\pi$	$4/9\pi$	$4/11\pi$	$4/13\pi$	$4/n\pi$
$\pi/3$	$12/\pi^2$	$24/3^2\pi^2$	$12/5^2\pi^2$	$-12/7^2\pi^2$	$-24/9^2\pi^2$	$-12/11^2\pi^2$	$12/13^2\pi^2$	$(24/\pi^2 n^2)\sin(n\pi/6)$
$\pi/2$	$16/\sqrt{2}\pi^2$	$16/3^2\sqrt{2}\pi^2$	$-16/5^2\sqrt{2}\pi^2$	$-16/7^2\sqrt{2}\pi^2$	$16/9^2\sqrt{2}\pi^2$	$16/11^2\sqrt{2}\pi^2$	$-16/13^2\sqrt{2}\pi^2$	$(16/\pi^2 n^2)\sin\frac{1}{4}n\pi$
$2\pi/3$	$6\sqrt{3}/\pi^2$	0	$-6\sqrt{3}/5^2\pi^2$	$6\sqrt{3}/7^2\pi^2$	0	$-6\sqrt{3}/11^2\pi^2$	$6\sqrt{3}/13^2\pi^2$	$(12/\pi^2 n^2)\sin\frac{1}{3}n\pi$
π	$8/\pi^2$	$-8/3^2\pi^2$	$8/5^2\pi^2$	$-8/7^2\pi^2$	$8/9^2\pi^2$	$-8/11^2\pi^2$	$8/13^2\pi^2$	$(8/\pi^2 n^2)(-1)^{\frac{1}{2}n-\frac{1}{2}}$

With the aid of this table and the results of Sections 2 II and 2 III it will now be easy to write down the equation to the M.M.F. wave for a uniformly distributed winding with full-pitch coils. In the following treatment we shall divide our windings into two main groups, namely, single-layer windings and double-layer windings, and, generally speaking, follow the classification of armature windings set out by Dr. S. P. Smith,* confining our attention to those cases which are shown in his paper to be of practical importance.

I. *Single-layer windings.*—Single-layer windings constitute an important class owing to their wide usage for alternator and induction-motor stators. For this reason, therefore, and for the reason that the M.M.F. properties of all other windings can be deduced from the results found for them, we shall consider single-layer windings first and in some detail.

We shall assume that I is the root-mean-square value of the phase current, and that there are z conductors per pole-pitch. Then, if z' be the number of conductors in the current sheet forming the phase band, it is clear that $\frac{1}{2}z'\sqrt{2}\,\mathrm{I}$ is the maximum ampere-turns per pole and phase, so that

$$\overline{\mathrm{F}}_{\max} = 0{\cdot}4\,\pi\frac{z'}{2}\sqrt{2}\,\mathrm{I} = 0{\cdot}4\,\pi\frac{\sigma z}{2\pi}\sqrt{2}\,\mathrm{I} = \mathrm{K}\frac{\sigma}{\pi} \quad . \quad (10)$$

since $\qquad z'/\sigma = z/\pi$; and $\mathrm{K} = 0{\cdot}4\,\pi z \mathrm{I}/\sqrt{2}$.

$\overline{\mathrm{F}}_{\max}$ is of course measured in units of magnetomotive force, and we can now insert it in our equations for the following kinds of windings :—

(*a*) *Single-phase winding with various phase-spreads.*—The magnetomotive force of a single-phase winding is obviously pulsatory, its space distribution around the periphery being dependent only on the phase-spread. For example, the whole periphery could be wound (see Fig. 2 (*c*) i) with coils so that $\sigma = \pi$, the M.M.F. being then distributed according to a triangular wave. Owing to reasons of practical economy it is not often that such a winding is employed, the value of σ being reduced as a rule to $2\pi/3$ (see Fig. 2 *b*). The M.M.F. wave has then a trapezoidal shape. If we now give the equations to the waves for these two cases ($\sigma = \pi$ and $\sigma = 2\pi/3$) it will be sufficient indication of the method to be followed for any other value of σ arising in technical work.

(i) *Phase-spread, $\sigma = \pi$.*—From Equation (10) we have at once $\overline{\mathrm{F}}_{\max} = \mathrm{K}$; and from Table 1, $b_n = (8/\pi^2 n^2)(-1)^{\frac{1}{2}n-\frac{1}{2}}$,

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* S. P. SMITH: *Journal I.E.E.*, 1917, vol. 55, p. 18.

[illegible] $= (-1)^{n-1}$. Thus, remembering that we have assumed that the current follows a cosine law, the equation to the pulsating M.M.F. wave becomes

$$f = \sum F_n \sin n\theta \cos\omega t = [illegible]\, K \cos\omega t \Big[\sin\theta - \frac{1}{3}\sin 3\theta + [illegible] + \frac{1}{5}\sin 5\theta - \frac{1}{7}\sin 7\theta + \dots\Big] \quad (11)$$

This is clearly a pulsating rectangle of amplitude $= K$.

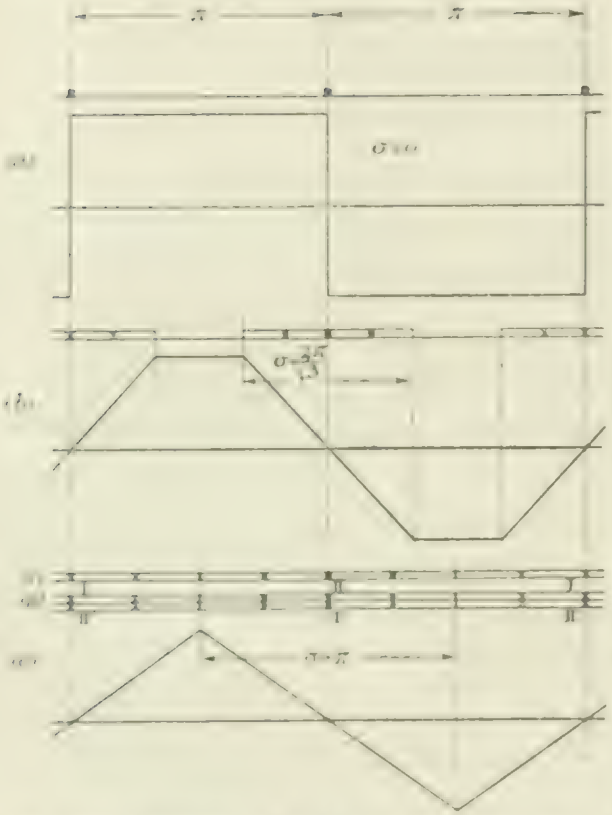

FIG. [illegible] of M.M.F. due to a current sheet of [illegible]

(a) [illegible]

(b) [illegible]

(c) [illegible]

(ii) " " " two layers.

[illegible] Equation [illegible] (10) gives $F_{max} = [illegible] K$, and Table 1 shows that [illegible] $\sin n\frac{\pi}{3}$. [illegible] giving as the equation of the pulsating M.M.F. wave

$$f = \sum [illegible] \Big[[illegible] \sin 5\theta + [illegible] - \frac{1}{11}\sin 11\theta + \dots \Big] \quad (12)$$

[illegible] is clearly [illegible] an odd multiple of [illegible] vanish from the wave. This is a perfectly general result, since any desired harmonic can be suppressed in the M.M.F. wave by suitable choice of σ; for example, if $\sigma = [illegible]$, [illegible] in the expression for [illegible] whenever n is a multiple of 7, and so no 7th or multiple of the 7th harmonic will appear in the wave.

[illegible] the phase currents in the two windings in Fig. [illegible] for the instants when $\omega t = 0$ and [illegible] together with the

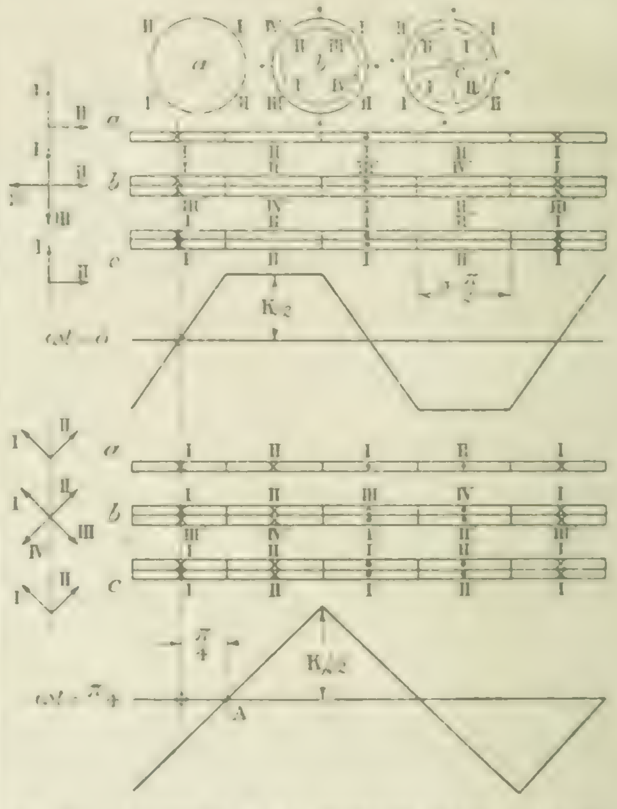

FIG. [illegible] M.M.F. [illegible] when [illegible] $\pi/4$.

(a) Single-layer winding [illegible] 2-phase system of currents.

(b) Double-layer, closed winding symmetrical 4-phase system of currents.

(c) [illegible]

corresponding M.M.F. waves. [illegible] Equation [illegible] becomes $F_{max} = \frac{1}{2}K$, and the value of [illegible] from Table 1 is [illegible]

[illegible] they produce in the winding can be determined at once from Section [illegible] readily find that the M.M.F. harmonics present are those of the order [illegible], the former harmonics having expressions deduced from Equation [illegible] and the latter from Equation [illegible], by putting $N = 2$ and the value of B_n just found above. Carrying out these substitutions we readily find as the equation to the M.M.F. wave,

$$F = \frac{16}{\sqrt{2}\,\pi^2} \cdot \frac{K}{2} \Big[\sin(\theta - \omega t) + \frac{1}{3^2} \sin(3\theta + \omega t) - \frac{1}{5^2} \sin(5\theta - \omega t) - \frac{1}{7^2} \sin(7\theta + \omega t) + \ldots \Big] \quad (13)$$

Putting $\omega t = 0$ in this equation gives

$$F = \frac{16}{\sqrt{2}\,\pi^2} \cdot \frac{K}{2} \Big[\sin\theta + \frac{1}{3^2} \sin 3\theta - \frac{1}{5^2} \sin 5\theta - \frac{1}{7^2} \sin 7\theta + \ldots \Big]$$

which is the equation to a trapezium in which $\sigma = \pi/2$ (see Table 1 for the relative values and signs of the harmonics), a fact verified by Fig. 3. The maximum value of this trapezoidal wave is readily found by putting $\theta = \pi/4$, thus :—

Maximum height of trapezoidal wave shape

$$= \frac{16}{\sqrt{2}\,\pi^2} \cdot \frac{K}{2} \Big[1 + \frac{1}{3^2} + \frac{1}{5^2} + \frac{1}{7^2} + \ldots \Big] \frac{1}{\sqrt{2}} = K/2,$$

since the sum of the bracketed series is $\pi^2/8$.

Now we have seen (Section 2 I (*a*)) that the *n*th harmonic in the M.M.F. wave moves at $1/n$th of synchronous speed in a direction dependent on its order. Let us suppose that the fundamental of the wave has moved forward a quarter of its wave-length, namely $2Y/4$. Then remembering that the $(4k + 1)$th harmonics move with and the $(4k - 1)$th harmonics against (see Equation 13) the fundamental, the relative motion between the fundamental and the harmonics will be

for the 3rd harmonic $2\,Y/4 + \frac{1}{3}(2\,Y/4) = 2\,Y/3$;
,, 5th ,, $2\,Y/4 - \frac{1}{5}(2\,Y/4) = 2\,Y/5$;
,, 7th ,, $2\,Y/4 + 1/7\,(2\,Y/4) = 2\,(2\,Y/7)$;

and so on. That is to say, the relative position of all the harmonics with respect to the fundamental is the same at the end of each quarter period as it was at the beginning, since in that time each harmonic has moved along its own wave-length (or some multiple thereof) relative to the principal or fundamental wave. Hence, at the end of every quarter period the distribution of M.M.F. is the same as at the beginning thereof, only advanced a quarter of a wave-length in space, a result whose general truth will be proved in Section 3 V.

If we examine in a similar way the state of affairs obtaining when $\omega t = \pi/4$, we shall find that the relative movement between the fundamental and the harmonics will be

for the 3rd harmonic $2\,Y/8 + \frac{1}{3}(2\,Y/8) = \frac{1}{2}(2\,Y/3)$;
,, 5th ,, $2\,Y/8 - \frac{1}{5}(2\,Y/8) = \frac{1}{2}(2\,Y/5)$;
,, 7th ,, $2\,Y/8 + 1/7\,(2\,Y/8) = (2\,Y/7)$;

and so on. That is, the 3rd, 5th, etc., harmonics have travelled one-half their respective wave-lengths relative to the fundamental and so are reversed with respect thereto, whilst the 7th, etc., harmonics have moved a whole wave-length and therefore have their relative positions unaltered. As we shall presently see, this rearrangement of the harmonics leads to a triangular wave shape transposed in space by $\pi/4$.

Referring to Fig. 3, we can refer the wave to its own origin when $\omega t = \pi/4$ by putting $\theta = \theta' + \pi/4$ in Equation (13) together with this value of ωt, giving on reduction,

$$F_{\theta'} = \frac{16}{\sqrt{2}\,\pi^2} \cdot \frac{K}{2} \Big[\sin\theta' - \frac{1}{3^2} \sin 3\theta' + \frac{1}{5^2} \sin 5\theta' - \frac{1}{7^2} \sin 7\theta' + \ldots \Big]$$

as the equation to the wave referred to the point A as origin. Reference to Table 1 will show that the signs of the harmonics are those of a triangle, whose maximum height is found by making $\theta' = \pi/2$, giving

Maximum height of triangular wave shape $= K/\sqrt{2}$.

It will be seen from the equation for $F_{\theta'}$ that the signs of the harmonics are those predicted by the above argument.

Hence we see that the M.M.F. wave of a hemi-symmetrical two-phase winding moves around the periphery of the armature at synchronous speed, pulsating in shape between a trapezoidal and a triangular form eight times in a period. Between these two limiting shapes there are a number of transitional forms which we shall have occasion to consider further in Section 3 V.

(*c*) *Symmetrical three-phase winding.*—In this case the distribution of the phase currents will be as shown in Fig 4(*a*), where the instants when $\omega t = 0$ and $\omega t = \pi/6$ are depicted. Since in a symmetrical three-phase winding $\sigma = \pi/3$, we get from Equation (10) and Table 1,

$$B_n = \tfrac{1}{3} K\,(24/\pi^2 n^2) \sin(n\,\pi/6).$$

The phase currents form a symmetrical three-phase system in which $N = 3$ and therefore $\beta = 2\pi/3$, and so the harmonics present in the M.M.F. wave can be determined at once from Section 2 II (*a*). Referring for a moment to Section 2 II (*b*), we see that since N is odd, no harmonics will be present whose orders are odd multiples of 3 ; the wave will thus be devoid of 3rd, 9th, 15th, etc., harmonics. From Section 2 II (*a*) the existent harmonics are those of the order $n = 2kN \pm 1 = 6k + 1$ and $6k - 1$, the expressions for the former being deduced from Equation 5 (*c*) and for the latter from Equation 5 (*b*) by inserting $N = 3$ with the above value of B_n and the proper value of *n*, giving as the equation to the wave of magnetomotive force,

$$F = \frac{18}{\pi^2} \cdot \frac{K}{3} \Big[\sin(\theta - \omega t) + \frac{1}{5^2} \sin(5\theta + \omega t) - \frac{1}{7^2} \sin(7\theta - \omega t) - \frac{1}{11^2} \sin(11\theta + \omega t) + \ldots \Big] \quad (14)$$

By putting $\omega t = 0$, we have,

$$F = \frac{18}{\pi^2} \cdot \frac{K}{3} \Big[\sin\theta + \frac{1}{5^2} \sin 5\theta - \frac{1}{7^2} \sin 7\theta - \frac{1}{11^2} \sin 11\theta + \ldots \Big]$$

as the equation to the shape of the wave when $t = 0$. This is the well-known Fourier's series* for the pointed wave-form shown in Fig. 4 for this instant of time. Putting $\theta = \pi/2$ we readily prove that the

Maximum height of pointed wave-shape

$$= \frac{18}{\pi^2} \cdot \frac{K}{3} \Big[1 + \frac{1}{5^2} + \frac{1}{7^2} + \frac{1}{11^2} + \ldots \Big] = \frac{2}{3} K,$$

since the sum of the series then becomes $\pi^2/9$.

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* S. P. Smith and W. H. Barling, *Electrician*, 1914, vol. 74, p. 43.

If we examine the relative motion between the harmonics and the fundamental when $\omega t = \pi/3$, that is, one-sixth of a period later, we shall find the following results. Since in that time the fundamental has moved forward one-sixth of a wave-length, i.e. $2Y/6$, we get for the relative motion between the fundamental and the harmonics :—

for the 5th harmonic $2Y/6 + \frac{1}{5}(2Y/6) = 2Y/5$;
" 7th " $2Y/6 - 1/7\,(2Y/6) = 2Y/7$;
" 11th " $2Y/6 + (1/11)(2Y/6) = 2(2Y/11)$;

and so on. This follows when we remember that the $(6k+1)$th harmonics move with and the $(6k-1)$th harmonics against the fundamental at speeds inversely proportional to their respective orders. Thus we see that at the end of every one-sixth of a period the relative positions of the harmonics and the fundamental are interchanged and the wave-shape is consequently the same as at the beginning of that interval, only advanced one-sixth of a wave-length around the periphery. This is easily deduced from the above table, which shows that in that interval every harmonic has moved through some multiple of its own wave-length relatively to the fundamental.

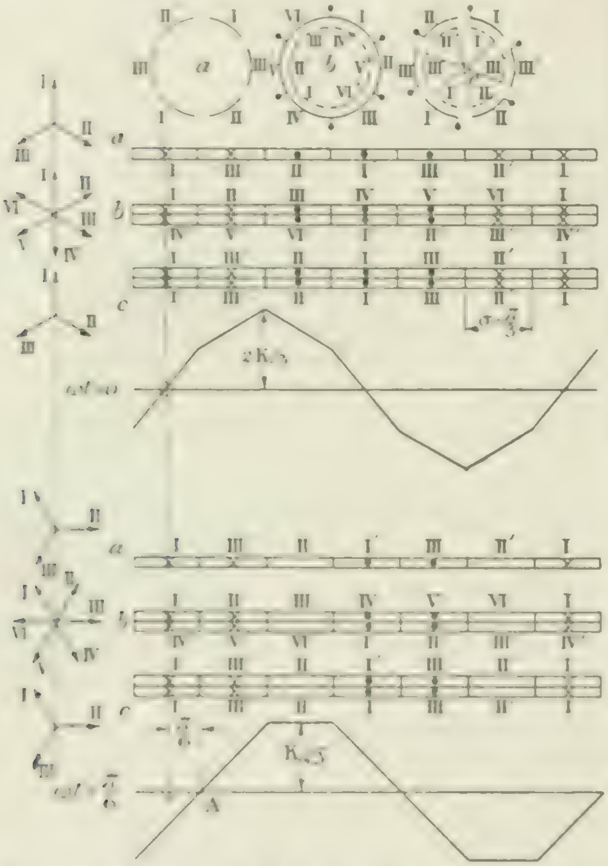

FIG. 4.—Two Shapes of M.M.F. wave due to a uniformly distributed winding with [illegible] (when $\omega t = 0$ and $\omega t = \pi/6$).

(a) [illegible] winding; symmetrical 3-phase system of currents.
(b) Double-layer closed winding; symmetrical 6-phase system of currents.
(c) Double-layer open winding; symmetrical 3-phase system of currents.

In a like fashion, determining the relative movement when $\omega t = \pi/6$, gives

for the 5th harmonic $2Y/12 + \frac{1}{5}(2Y/12) = Y/5$;
" 7th " $2Y/12 - (1/7)(2Y/12) = Y/7$;
" 11th " $2Y/12 + (1/11)(2Y/12) = 2Y/11$;
" 13th " $2Y/12 - (1/13)(2Y/12) = 2Y/13$;

and so on. That is, the 5th and 7th, etc., harmonics have travelled through half their respective wave-lengths relative to the fundamental and so are reversed in phase; whereas the 11th, 13th, etc., have moved a whole number of their respective wave-lengths, so that their relative positions remain unaltered. This re-arrangement of the sign of the harmonics at this instant gives rise to a trapezoidal wave in which $\sigma = 2\pi/3$, as we can readily show as follows :—Putting $\omega t = \pi/6$ and referring the equation to the zero point of the wave (the point A in Fig. 4) by making $\theta = \theta' + \pi/6$ in Equation (14), we get

$$F_\theta = \frac{18}{\pi^2}\cdot\frac{K}{3}\left[\sin\theta' - \frac{1}{5^2}\sin 5\theta' + \frac{1}{7^2}\sin 7\theta' - \frac{1}{11^2}\sin 11\theta' + \dots\right]$$

which, as Table I will show, is a trapezium in which $\sigma = 2\pi/3$. Making $\theta' = \pi/3$ gives

Maximum height of trapezoidal wave-shape

$$= \frac{18}{\pi^2}\cdot\frac{K}{3}\left[1 + \frac{1}{5^2} + \frac{1}{7^2} + \frac{1}{11^2} + \dots\right]\frac{\sqrt{3}}{2} = \frac{K}{\sqrt{3}}.$$

Hence, the M.M.F. wave of a symmetrical three-phase winding moves around the periphery of the armature at synchronous speed, pulsating in shape between a pointed and a trapezoidal form 12 times in a period.

II. *Closed double-layer windings.*—Having completed our consideration of the practical cases of single-layer windings, we must now turn our attention to the case of windings in which the current sheets are arranged in two layers. Speaking generally, double-layer windings can be broadly divided into two classes, namely, closed and open windings, the present subsection being confined to a consideration of the former. With a closed winding the phase currents are applied by tapping the winding at points separated from each other by the appropriate phase-pitch; and we shall take as the phase current the current flowing in the conductors of the current sheets lying between a pair of consecutive tappings, denoting its R.M.S. value as before by I. The current sheet constituting the spread of a phase will then be the sector of the winding lying in one layer between two adjacent tappings (see Figs. 3 b, 4 b and c). It will thus be apparent that $\sigma/\beta = [illegible]$, whence

$$I_{\max} = 0.4\pi\frac{Z}{2}\sqrt{2}\,I = 0.4\pi\frac{[illegible]}{2\pi}\sqrt{2}\,I = K\frac{\sigma}{[illegible]} \quad . \quad (15)$$

is the maximum magnetomotive force per pole and phase.

With this definition of a "phase" in our minds we can pass on to consider the cases arising in practical work, but before doing so it should be noted that this definition has been chosen in order to simplify the problem as much as possible. It will be clear that the M.M.F. of the winding depends on the *actual* current in the conductors (as we are to consider) and has no reference at all to the manner in which that current enters the winding, whether as the result of a "diametral" system of loading or of a "polygon" system.

(*a*) *Two tappings, π radians apart.*—This winding constitutes the common double-layer single-phase winding usually found in single-phase converters. From the point of view of our classification, however, it is really a symmetrical two-phase winding ($\beta = 2\,\pi/2 = \pi$) with the phases in parallel. Treating it as such, the distribution of current sheets will appear as in Fig. 2 (*c*) ii; giving rise to a pulsating triangular wave of M.M.F., as was found for the single-layer winding with $\sigma = \pi$, Fig. 2 (*c*) i. Putting $\sigma = \pi$ in Equation (15) gives $\overline{F}_{\max} = K/2$, and by analogy with Equation (11), $B_n = \frac{1}{2} K\,(8/\pi^2 n^2)\,(-1)^{\frac{1}{2}n - \frac{1}{2}}$, so that

$$F = 2\sum_{1}^{\infty} B_n \sin n\,\theta \cos\omega t = \frac{8}{\pi^2}\cdot\frac{2K}{2}\,.\cos\omega t\left[\sin\theta - \frac{1}{3^2}\sin 3\,\theta + \frac{1}{5^2}\sin 5\,\theta - \frac{1}{7^2}\sin 7\,\theta + \ldots\right]$$

which is identical with Equation (11).

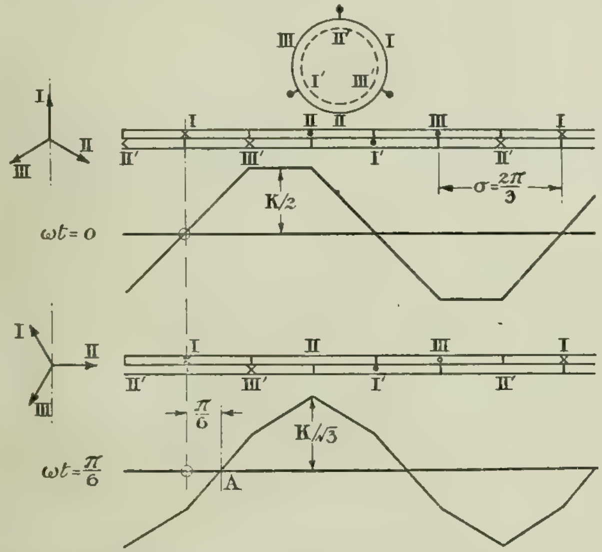

FIG. 5.—The shapes of M.M.F. wave due to a uniformly distributed winding with full-pitch coils; when $\omega t = 0$ and $\pi/6$. Phase-spread, $\sigma = 2\,\pi/3$.

Double-layer closed winding; symmetrical 3-phase system of currents.

(*b*) *Four tappings, $\pi/2$ radians apart.*—The distribution of current sheets in this case is given in Fig. 3 (*b*), and will be seen to correspond exactly with those set out in Fig. 3 (*a*) for a hemisymmetrical two-phase winding, for which we calculated the M.M.F. equation in Section 3 I (*b*). Referring to this section we see that: (i) σ is the same therein as in the present case, namely $\sigma = \pi/2$; (ii) the value of $\overline{F}_{\max}$ is twice the value in the present case, namely K/2, as against K/4 found from Equation (15) by putting $\sigma = \pi/2$; (iii) the number of phases, N = 2, in the former case is half the present value, namely N = 4. Hence, the value of $\frac{1}{2} N B_n$ is the same for the two cases and the equation to the M.M.F. wave is therefore applicable here, namely Equation (13). Hence Equation (13) is the equation to the M.M.F. wave of a closed double-layer winding with four tappings at a phase-pitch of $\pi/2$ radians.

(*c*) *Three tappings, $2\,\pi/3$ radians apart.*—The phase-spread is $\sigma = 2\,\pi/3$ in this case, and as it is not usual to have a single-layer winding with this phase-spread we must consider this case on its merits. The current sheets are shown for $\omega t = 0$ and $\omega t = \pi/6$ in Fig. 5, together with the corresponding M.M.F waves.

As deduced for the single-layer three-phase winding (Section 3 I (*c*)) the only harmonics present are those of order $n = 6k + 1$ and $6k - 1$, the equations for which are found from Section 2 II (*a*), no multiples of 3 occurring at all. For $\sigma = 2\,\pi/3$ the value of b_n from Table 1 is $b_n = (12/\pi^2/n^2)\sin n\,\pi/3$, and from Equation (15) $\overline{F}_{\max} = K/3$, so that $B_n = (K/3)\,.\,(12/\pi^2 n^2)\sin n\,\pi/3$.

Using this in Equations 5 (*b*) and 5 (*c*) for N = 3 and the appropriate value of n we get as the equation to the M.M.F. wave

$$F = \frac{9\sqrt{3}}{\pi^2}\cdot\frac{K}{3}\left[\sin(\theta - \omega t) - \frac{1}{5^2}\sin(5\,\theta + \omega t) + \frac{1}{7^2}\sin(7\,\theta - \omega t) - \frac{1}{11^2}\sin(11\,\theta + \omega t) + \ldots\right] \quad (16)$$

By putting $\omega t = 0$ the shape of the wave when $t = 0$ is a trapezium in which $\sigma = 2\,\pi/3$, as the substitution will readily prove; thus,

$$F = \frac{9\sqrt{3}}{\pi^2}\cdot\frac{K}{3}\left[\sin\theta - \frac{1}{5^2}\sin 5\theta + \frac{1}{7^2}\sin 7\theta - \frac{1}{11^2}\sin 11\theta + \ldots\right]$$

Substituting $\theta = \pi/3$ we get

Maximum height of trapezoidal wave-shape

$$= (9\sqrt{3}/\pi^2)\,(K/3)\,(\pi^2/9)\,(\sqrt{3}/2) = K/2.$$

An argument similar to that applied to case (*c*) of Section 3 I will show that the wave-shape is repeated at intervals of one-sixth of a period and oscillates 12 times in a cycle between the trapezoidal shape just considered and the peaked form occurring when $\omega t = \pi/6$. Putting $\omega t = \pi/6$ in Equation (16) and referring the wave to its own zero point, A, as origin by making $\theta = \theta' + \pi/6$, we have

$$F_{\theta'} = \frac{9\sqrt{3}}{\pi^2}\cdot\frac{K}{3}\left[\sin\theta' + \frac{1}{5^2}\sin 5\,\theta' - \frac{1}{7^2}\sin 7\,\theta' - \frac{1}{11^2}\sin 11\,\theta' + \ldots\right]$$

which is the expression for the pointed wave-shape. Making $\theta' = \pi/2$ gives

Maximum height of pointed wave-shape

$$= (9\sqrt{3}/\pi^2)\,(K/3)\,(\pi^2/9) = K/\sqrt{3}.$$

(*d*) *Six tappings, $\pi/3$ radians apart.*—In this case we have a symmetrical six-phase winding with $\sigma = \pi/3$, and comparing the current sheets (Fig. 4*b*) with those for a single-layer winding with three phases and the same phase-spread (Fig. 4*a*) we see that so far as M.M.F. is concerned the [illegible] ½ N B, is also the same. Hence, the equation to the [illegible]

A winding of this class is the one commonly employed in a rotary converter with six slip-rings, and the phase currents are the result of "diametral" loading on the generator, which in that case is of the normal three-[illegible]

III. *Opened double-layer windings.*—We must now consider opened double-layer windings, the technical importance of which is increasing owing to their application to alternator stators and induction-motor rotors.

The mode of opening a double-layer winding is well-known* and we need not enter into the matter here. It [illegible] N radians apart for an N-phase open winding) are located in the winding at the appropriate phase-pitch apart, just as in the case of a closed winding tapped for phases. Instead of tappings being applied to these points, the winding is there opened, and the oppositely situated parts of the winding (being in opposition of phase) are then joined in series or parallel as desired. The composite phases so formed can be star- or mesh-connected according to circumstances. With these preliminary remarks we can pass on to the consideration of two important cases.

[illegible] Fig. 3(*b*), where the current sheets of a closed double-layer winding with four tappings are shown, it is easy to see that [illegible] form a single-phase, if the winding were opened at the [illegible] bine to form the second phase of the winding, this new phase being displaced from the first composite phase by [illegible] two-phase system of currents (of the same R.M.S. value as in the closed winding) would then produce exactly the same distribution of peripheral loading in the open winding as was produced by a symmetrical four-phase system of currents in the closed winding from which it was derived. Hence, the wave of M.M.F. will be the same in the two cases and we can say that the equation to the M.M.F. wave of a hemisymmetrical two-phase open winding will be identical with that found for a closed wind-[illegible]

[illegible] bution at every instant as occurred in the closed winding [illegible] closed winding with six tappings $\pi/3$ radians apart, namely [illegible]

These results can be readily generalized by induction, leading us to the conclusion that the equation to the M.M.F. wave of an N-phase open winding is identical with that of a closed winding with 2 N equidistant tappings, since the phase-spread and peripheral distribution of current sheets are the same in both cases.

IV. *Discussion of results.*—In the preceding subsections we have deduced the equations to the M.M.F. wave of a uniformly distributed winding arranged for various numbers of phases, such as are found in practice. These equations give the value of the magnetomotive force at any point on the periphery of the armature for any instant of time, and the M.M.F. waves which they represent have many interesting and important properties worthy of tabulation and discussion, which can be conveniently considered under the following headings:—

(*a*) [illegible] *limiting forms of the wave of magnetomotive force.*—In many problems connected with armature reaction in alternators and in the elementary theory of the induction motor it is usual to neglect harmonics* in the M.M.F. wave and to deal only with the fundamental. It will therefore be useful if we have a table giving the amplitude of the fundamental in the M.M.F. wave for all the cases we have considered, and for this reason Table 2 has been prepared. The amplitudes of the limiting shapes of the wave have also been inserted, since they are useful in armature reaction problems where the extent of variation of M.M.F. must be known.

In Table 2, the quantity $K = 0{\cdot}4\,\pi\,z\,I/\sqrt{2}$, where z is the number of conductors per pole-pitch and $I =$ the R M S. current per phase, is a quantity readily calculated when the type of winding is specified. The amplitude of the fundamental is given as the product of two terms; the first is a numerical factor arising out of the Fourier analysis of the wave; whereas the second is the maximum magnetomotive force per pole and phase, F_{max}. The amplitudes and heights of the limiting forms of the waves are thus tabulated in units of magnetomotive force per pole, and to obtain them in ampere-turns per pole, the tabular values must be divided by $0{\cdot}4\,\pi$.

(*b*) *Direction of motion and speed of harmonics.*—Our previous analysis has shown that the moving M.M.F. wave can be split up into a number of harmonic waves of sinusoidal shape, the linear speed of the *n*th harmonic being 1/*n*th of that of the fundamental, and the direction of motion being also a function of the order of the harmonic.

In Table 3 the directions of motion of the harmonics in the M.M.F. wave of a uniformly distributed winding carrying sine currents are shown by an arrow-head drawn on a circle, and the speed relatively to the fundamental is indicated by a fraction enclosed in the circle. Similar tables have been published by E. Arnold in volume 3 of "Die Wechselstromtechnik," p. 330. With the aid of this table we can see the harmonics present (up to the 13th order) in the M.M.F. wave, together with their directions of motion and relative speeds.

(*c*) *Theory of the periodic change of shape of the M.M.F. wave.*—In dealing with the wave of M.M.F. produced by

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* [illegible]

* [illegible]

TABLE 2.

Amplitude of Fundamental and Heights of Limiting Shapes of the M.M.F. Wave of a Uniformly Distributed Winding.
$K = 0{\cdot}4\,\pi z I/\sqrt{2}$.

Number of Phases	Phase-spread, σ	Reference	Kind of Winding	Remarks	Equation to M.M.F. Wave	Amplitude of the Fundamental		Trianglar Shape		Trapezoidal Shape		Pointed Shape	
						Actual	Numerical Value	Height	ωt	Height	ωt	Height	ωt
1	π	Sect. 3 I (*a*) i	Single-layer	—	11	$\frac{8}{\pi^2} K$	0·811 K	K	0	—	—	—	—
1	π	" 3 II (*a*)	Closed double-layer	Two tappings, π radians apart	11	"	"	K	"	—	—	—	—
1	$2\pi/3$	" 3 I (*a*) ii	Single-layer	—	12	$\frac{6\sqrt{3}}{\pi^2} \cdot \frac{2K}{3}$	0·701 K	2 K/3	"	—	—	—	—
2	$\pi/2$	" 3 I (*b*)	Single-layer	—	13	$\frac{16}{\sqrt{2}\pi^2} \cdot \frac{K}{2}$	0·574 K	$K/\sqrt{2}$	$\pi/4$	K/2	0	—	—
4	$\pi/2$	" 3 II (*b*)	Closed double-layer	Four tappings, $\pi/2$ radians apart	13	"	"	"	"	"	"	—	—
2	$\pi/2$	" 3 III (*a*)	Open double-layer	—	13	"	"	"	"	"	"	—	—
3	$\pi/3$	" 3 I (*c*)	Single-layer	—	14	$\frac{18}{\pi^2} \cdot \frac{K}{3}$	0·609 K	—	—	$K/\sqrt{3}$	$\pi/6$	2 K/3	0
6	$\pi/3$	" 3 II (*d*)	Closed double-layer	Six tappings, $\pi/3$ radians apart	14	"	"	—	—	"	"	"	"
3	$\pi/3$	" 3 III (*b*)	Open double-layer	—	14	"	"	—	—	"	"	"	"
3	$2\pi/3$	" 3 II (*c*)	Closed double-layer	Three tappings, $2\pi/3$ radians apart	16	$\frac{9\sqrt{3}}{\pi^2} \cdot \frac{K}{3}$	0·527 K	—	—	K/2	0	$K/\sqrt{3}$	$\pi/6$

TABLE 3.

Direction of Motion and Speed of Harmonics in the M.M.F. Wave of a Uniformly Distributed Winding carrying Sinusoidal Currents.

No. of Phases	Phase-spread, σ	Reference	Type of Winding	Remarks	Equation to M.M.F. Wave	Direction of Motion and Speed						
						1st	3rd	5th	7th	9th	11th	13th
1	π	Sect. 3 I (*a*) i	Single-layer	—	11	All harmonics present ; pulsating wave						
1	π	" 3 II (*a*)	Closed double-layer	Two tappings, π radians apart	11	"	"		"		"	"
1	$2\pi/3$	" 3 I (*a*) ii	Single-layer	—	12	Multiples of 3 present. Remaining harmonics pulsating.						
2	$\pi/2$	" 3 I (*b*)	Single-layer	—	13	↺ 1	↻ 1/3	↺ 1/5	↻ 1/7	↺ 1/9	↻ 1/11	↺ 1/13
4	$\pi/2$	" 3 II (*b*)	Closed double-layer	Four tappings, $\pi/2$ radians apart	13							
2	$\pi/2$	" 3 III (*a*)	Open double-layer	—	13							
3	$\pi/3$	" 3 I (*c*)	Single-layer	—	14	↺ 1		↻ 1/5	↺ 1/7		↻ 1/11	↺ 1/13
6	$\pi/3$	" 3 II (*d*)	Closed double-layer	Six tappings, $\pi/3$ radians apart	14							
3	$\pi/3$	" 3 III (*b*)	Open double-layer	—	14							
3	$2\pi/3$	" 3 II (*c*)	Closed double-layer	Three tappings, $2\pi/3$ radians apart	16							

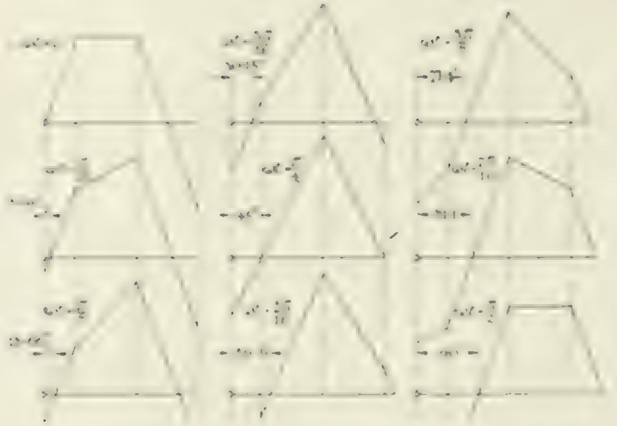

FIG. 6.—The shapes assumed by the M.M.F. wave of a [illegible] winding with [illegible] coils, at intervals of [illegible] of a period. [illegible]

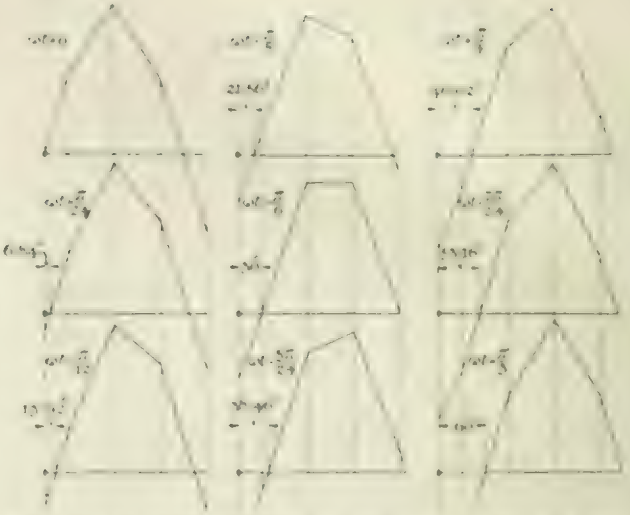

FIG. 7.—The shapes assumed by the M.M.F. wave of a [illegible] winding with full pitch coils at intervals of [illegible] of a period. [illegible]

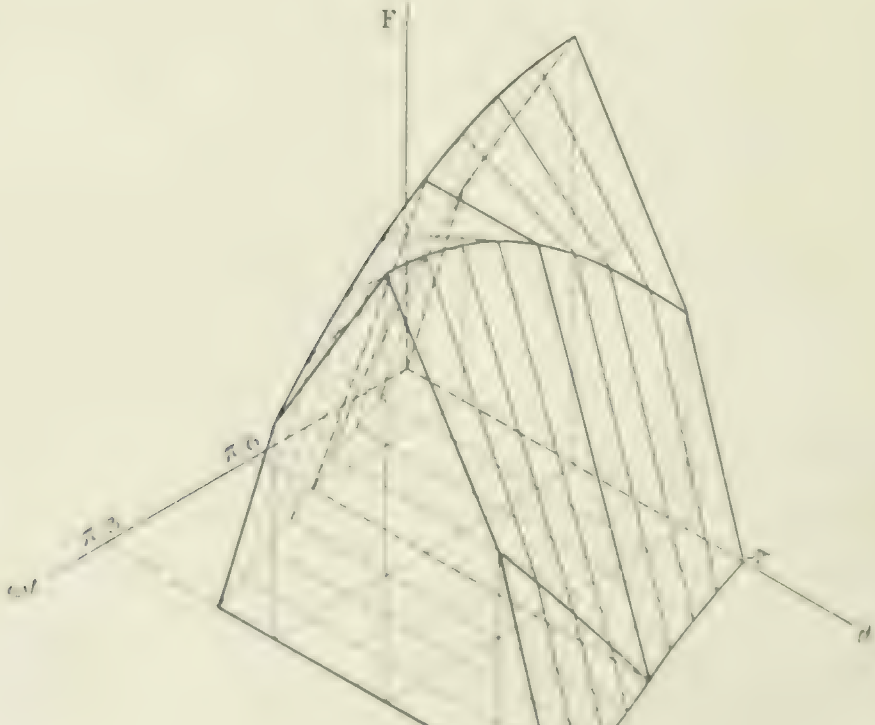

FIG. 8.—[illegible] model showing the M.M.F. wave of a [illegible] winding [illegible]

various polyphase windings, we have seen that the shape of the wave changes cyclically between certain limiting forms. For three- and six-phase windings these limiting forms are a trapezoidal and a pointed wave; whilst in the case of two- and four-phase windings the shape changes periodically from a trapezium to a triangle and back again. We showed, in dealing with individual cases, how the recurrence of the limiting shapes could be predicted by consideration of the relative motion taking place between the fundamental and the harmonics in the wave; and it will now be our object to generalize the arguments which we have used for the purpose of the prediction.

It will be obvious that whatever shape the changing M.M.F. wave may have, that shape will be repeated (advanced further around the periphery) when all harmonics have moved some integral multiple of their respective wave-lengths relative to the fundamental. Let us assume that the repetition of any given wave-form takes place when the fundamental has moved some fraction ζ of its wave-length, i.e. when it has advanced by $2Y\zeta$ cm. around the armature periphery. Then, since the nth harmonic wave moves at $1/n$th of synchronous speed, it has advanced or receded by $2Y\zeta/n$ cm. Remembering that harmonics of order $2kN+1$ move in the same direction as the fundamental, and those of order $2kN-1$ in the opposite direction, we have for the relative movement between the fundamental and the nth harmonic,

$$2Y\zeta - 2Y\zeta/n \text{ when } n = 2kN+1$$

and

$$2Y\zeta + 2Y\zeta/n \text{ when } n = 2kN-1.$$

For a shape to repeat, these expressions must equal an integral multiple of wave-lengths of the harmonic under consideration, i.e. $m(2Y/n)$, where m is any integer. Combining the two expressions gives

$$\zeta[2Y \mp (1/n)\,2Y] = m\,2Y/n;$$

or

$$\zeta = m/(n \mp 1) = m/(2kN),$$

since the upper sign applies when $n = 2kN+1$ and the lower when $n = 2kN-1$. Thus, the condition to be fulfilled is, $2kN\zeta =$ an integer, for all values of k.

For example, if $N = 2$, we have $4k\zeta =$ an integer, which is clearly satisfied when $\zeta = \frac{1}{4}$ or any multiple of $\frac{1}{4}$. Hence, the shape or the M.M.F. wave of a two-phase winding recurs after every quarter period, the wave having moved along a quarter of the fundamental wave-length.

Likewise, when $N = 3$, we get $6k\zeta =$ an integer, which is true when $\zeta = 1/6$ or any multiple thereof. Hence the shape of the M.M.F. wave of a three-phase winding recurs after every one-sixth of a period, the wave having moved along by successive sixths of the fundamental wave-length.

When N is an even number > 2, there are in addition to harmonics of order $2kN \pm 1$, others given by $kN \pm 1$; which give as an auxiliary condition, $kN\zeta =$ an integer, as well as $2kN\zeta =$ an integer for all values of k. Any value of ζ satisfying this new condition will clearly fulfil the old, and so we must find ζ so that $kN\zeta =$ an integer for all values of k.

Applying this result when $N = 4$, gives $4k\zeta =$ an integer, from which $\zeta = \frac{1}{4}$ or any multiple of $\frac{1}{4}$. Hence the periodic change of shape is the same for the M.M.F. wave of a four-phase winding as for a two-phase winding (c.f. Section 3, I (*b*) and III *a*) with II (*b*)).

Likewise, for $N = 6$, $6k\zeta =$ an integer, satisfied by $\zeta =$ multiples of $1/6$. Thus the periodic change of shape is the same for the M.M.F. wave of a six-phase winding as for a three-phase winding (c.f. Section 3 I (*c*), II (*c*), and III (*b*) with II (*d*)).

Having now obtained the period of oscillation of and the limiting shapes assumed by M.M.F. waves of three- and six-phase and of two- and four-phase windings, it will be of interest if we now observe the shapes assumed by the waves in these two cases during the transition from one limiting form to the other. For this purpose, Figs. 6 and 7 have been prepared to show the various shapes passed through by the M.M.F. waves; and the author is of the belief that the results which they present are quite original. Since the wave of the M.M.F. is a function of two variables, namely, time t and space θ, the use of a three-dimensional model* to represent it will be obvious; and Fig. 8 is an isometric drawing of such a model for a three-phase

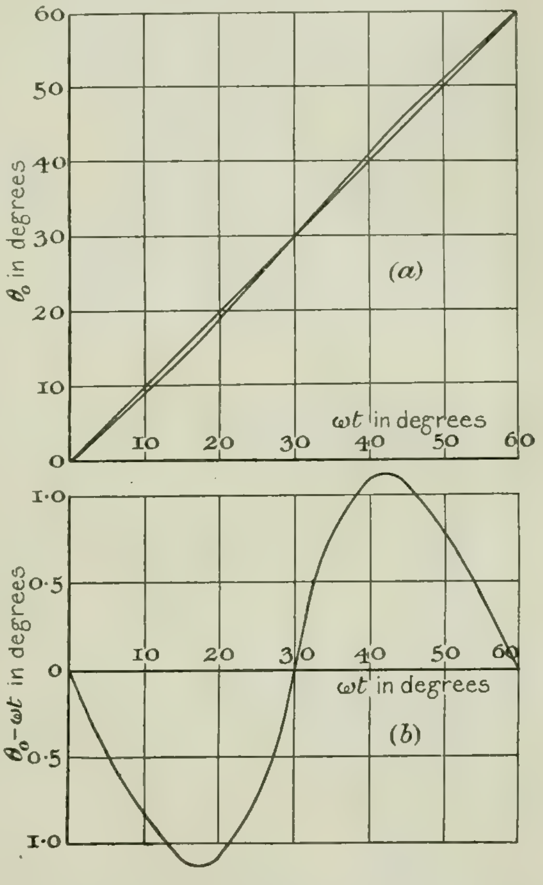

FIG. 9.—The deviation from exact synchronism of the speed of the zero point of the M.M.F. wave produced by a uniformly distributed 3-phase winding with full-pitch coils.

(*a*) The actual space-angle, θ_0, moved through by the zero point of the wave.

(*b*) The deviation, $\theta_0 - \omega t$, of the actual motion from synchronism.

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* Similar models are employed in the study of crystallography and solid geometry, and form excellent subjects for stereoscopic photography.

M.M.F. wave. Thus the M.M.F. at any value of θ and t is given by the height of the model from the ground plane at that point; and a model of this kind has been actually constructed by means of intersecting cardboard waves drawn for various values of θ constant and t constant; the former groups of waves being clearly sine waves (since the magnetomotive force of a phase pulsates sinusoidally), cutting the ground system at right angles.

In Section 3 it was pointed out that the wave of M.M.F. [illegible] at an irregular speed, and Figs. 9 (a) and (b) [illegible]led to illustrate the point for the case of a three-phase M.M.F. wave. By studying the motion of the zero point of the wave (see Figs. 7 and 8) throughout one-sixth of a period it is possible to estimate the distance progressed thereby for a known value of ωt, and from the figures obtained Fig. 9 has been prepared. The inclined straight line in Fig. 9 (a) shows how far the wave would have gone had its speed been strictly uniform. The curve gives the actual movement of the wave, which is seen to be lagging behind the synchronous position in the first 1/12th of a period and leading ahead of it in the second 1/12th period. The difference between the line and the curve obviously represents the deviation of the motion of the wave from true synchronism and is shown in Fig. 9 (b).

By a similar process of analysis similar results can be proved for a two-phase M.M.F. wave, but they need not be given here.

5. THE EFFECT OF THE CONCENTRATION OF THE COILS IN SLOTTED ARMATURES UPON THE SHAPE OF THE M.M.F. WAVE DUE TO SINUSOIDAL PHASE CURRENTS IN FULL-PITCH COILS.

In all our preceding work (Section 3) we have assumed that the windings of the phases were perfectly uniformly spread out over the phase-band, the conductors being strictly contiguous and forming a current sheet of breadth equal to the phase-spread. Then, by assuming that the phases were supplied with sinusoidal currents, we have seen how to determine at any instant of time the distribution of magnetomotive force around the periphery of the armature. But in practice, armature windings are built up of coils whose sides are accommodated in slots arranged at suitable regular intervals around the circumference of the armature core; and this new grouping of the conductors will have a profound effect on the shape of the M.M.F. wave due to each phase, and therefore on that due to the whole winding. Both these M.M.F. waves will now be represented by stepped curves, instead of by the smooth geometrical shapes obtaining when the slot effect is not present. Our present object is therefore to find the equation to the M.M.F. wave due to a winding carrying sinusoidal currents, whose coil sides are accommodated in slots; and we shall assume that the coils composing the armature winding have a span of a full pole-pitch. As thus stated, the whole problem consists of a re-determination of B_n for any type of slotted armature with full-pitch coils; and we can readily attack it by dealing first with single-layer windings, since the other cases readily follow therefrom, as we have seen in Section 3.

1. *Single-layer winding with integral slots.*—It has been shown * that a single-layer winding having a whole number of slots per pole, Q, can be imagined to consist of coils of constant span,† generally a full-pitch. In Fig. 10 a single-layer winding having a whole number of slots per pole, Q and an integral number of slots per pole and phase, q, is shown, the actual coils of a phase being equivalent to the full-pitch coils A A, B B, C C. The M.M.F. wave for each coil is shown, the phase M.M.F. which they produce being drawn in the lower part of the figure by adding the M.M.F. waves of the individual coils. Let there be T_1 turns in a coil, and as before let I be the R.M.S. current per phase; then clearly,

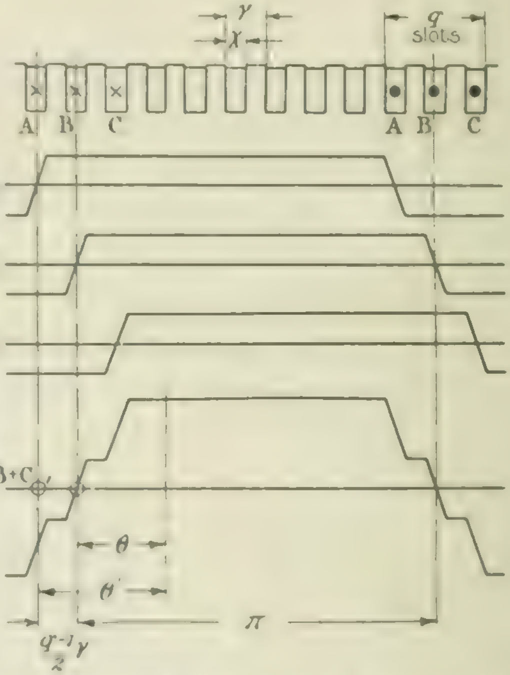

FIG. 10.—The pulsating wave of M.M.F. produced by one phase of a single-layer winding whose full-pitch coils are accommodated in slots; q = 3, Q = 9.

$$F_{max} = 0{\cdot}4\pi\sqrt{2}\,I\,.\,qT_1 = 0{\cdot}4\pi u' q I\sqrt{2} \quad . \quad . \quad (17)$$

since $T_1 = u'$ = number of conductors per slot carrying the current I. This equation replaces Equation (10) above.

Further, let γ = angular measure of slot pitch and χ = angular slot width,‡ then since the M.M.F. wave for each coil is a pulsating trapezium in which $\sigma = \chi$, we have on inserting this value in Equation (7) and taking a cosine law of current variation,

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* [illegible]

* [illegible] S. P. SMITH, *Journal I.E.E.*, [illegible]

† The span is [illegible] π when N is odd, and π − [illegible] when N is even.

‡ In the [illegible] the whole slot width χ is the [illegible] of the armature periphery of the conductor width.

$$\text{M.M.F. of first coil} = \frac{8\,\overline{F}_{\max}}{\pi\,\chi\,q}\cos\omega t\left\{\sin\theta'\sin\frac{\chi}{2} + \frac{\sin 3\,\theta'\sin(3\,\chi/2)}{3^2}+\dots\right\}$$

$$\text{M.M.F. of second coil} = \frac{8\,\overline{F}_{\max}}{\pi\,\chi\,q}\cos\omega t\left\{\sin(\theta-\gamma)\sin\frac{\chi}{2} + \frac{\sin 3\,(\theta-\gamma)\sin(3\,\chi/2)}{3^2}+\dots\right\}$$

$$\text{M.M.F. of third coil} = \frac{8\,\overline{F}_{\max}}{\pi\,\chi\,q}\cos\omega t\left\{\sin(\theta-2\,\gamma)\sin\frac{\chi}{2} + \frac{\sin 3\,(\theta'-2\,\gamma)\sin(3\chi/2)}{3^2}+\dots\right\}$$

and so on, so that

$$\text{M.M.F of } q\text{th coil} = \frac{8\,\overline{F}_{\max}}{\pi\,\chi\,q}\cos\omega t\left\{\sin[\theta-(q-1)\,\gamma]\sin\frac{\chi}{2} + \frac{\sin 3\,[\theta'-(q-1)\,\gamma]\sin(3\,\chi/2)}{3^2}+\dots\right\}$$

Summing these expressions for the q coils of a phase, we have as the equation to the phase M.M.F. wave referred to O′ as origin,

$$\frac{8\,\overline{F}_{\max}}{\pi\,\chi\,q}\cos\omega t\left\{\sin\left[\theta'-\tfrac{1}{2}(q-1)\gamma\right]\sin\frac{\chi}{2}\cdot\frac{\sin(q\,\gamma/2)}{\sin(\gamma/2)} + \frac{\sin 3\left[\theta'-\tfrac{1}{2}(q-1)\,\gamma\right]\sin(3\,\chi/2)}{3^2}\cdot\frac{\sin(3\,q\,\gamma/2)}{\sin(3\,\gamma/2)}+\dots\right\}$$

If we now transfer the origin to the middle of the phase-band by putting $\theta = \theta' - \frac{1}{2}(q-1)\,\gamma$, we have referred to the usual origin, O,

Phase M.M.F

$$= \frac{8\,\overline{F}_{\max}}{\pi\,\chi}\cos\omega t\sum_{n=1}^{n=\infty}\sin n\,\theta\,.\,\frac{\sin(n\,\chi/2)}{n^2}\,.\,\frac{\sin(n\,q\,\gamma/2)}{q\sin(n\,\gamma/2)}$$

$$= \frac{8\,\overline{F}_{\max}}{\pi\,\chi}\cot\omega t\sum_{n=1}^{n=\infty} f_{q,n}\,\frac{\sin(n\,\chi/2)}{n^2}\sin n\,\theta,$$

where $f_{q,n} = \sin(\frac{1}{2}\,n\,q\,\gamma)/q\sin(\frac{1}{2}\,n\,\gamma)$ = the distribution factor of the nth harmonic for q coils in series, tables for which have been calculated and published.*

From this result we have at once the coefficient in the Fourier's series,

$$B_n = \frac{8\,\overline{F}_{\max}}{\pi\,\chi}f_{q,n}\,\frac{\sin(n\,\chi/2)}{n^2} \quad . \quad . \quad . \quad . \quad (18)$$

in which the value of $\overline{F}_{\max}$ is given by Equation (17). When the slotting is known, B_n is determined and the values so obtained must be used in deducing the equations corresponding to Equations (11), (12), (13), and (14), taking account of slotting. Thus, to determine the effect of the slots on the shape of the M.M.F. wave, it is only necessary to employ the value of B_n appropriate to the case under consideration by using Equation (18) instead of Table I.* All our previous principles hold good, and the properties of the M.M.F. wave will clearly be unaffected by the slotting. The shape of the wave, however, will be exceedingly modified thereby, in virtue of the peculiar law which B_n now follows, and as in the pressure wave of an alternator certain harmonics will be reinforced, namely those of order $2\,w\,Q \pm 1$. Due to the appearance of these tooth ripples, and to the considerable diminution of some harmonics and relative augmentation of others, the steps to which we have already directed attention appear in the M.M.F. waves. An actual example will be worked out in the third part of the present section.

II. *Double-layer windings with full-pitch coils.*—In dealing with double-layer closed windings we saw that, with the exception of one case, the M.M.F. wave equation could be directly deduced from that of the single-layer winding with the same phase-spread. It will be clear that the fact that the coils are embedded in slots will in no wise affect this result; but the form for $\overline{F}_{\max}$ can be written rather more conveniently for double-layer windings in the following way:—

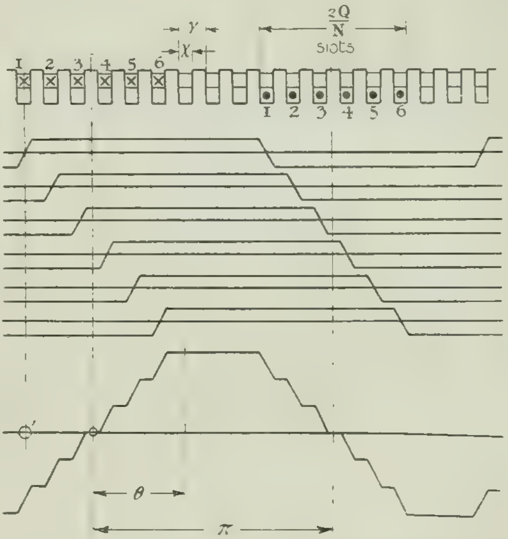

FIG. 11.—The pulsating wave of M.M.F. produced by one phase of a closed double-layer winding whose full-pitch coils are accommodated in slots ($Q = 9$).

Referring to Fig. 11, where the coil-sides of one phase in a closed winding are shown, it is clear that the actual coils 11, 22, 33, etc., of the winding can be regarded as being the coils of a single-layer winding with full-pitch coils each containing $\frac{1}{2}\,u\,T_c$ turns, u being the number of coil-sides per slot in the double-layer winding and T_c the number of turns per coil. Thus we can replace u' in Equation (17) by $u\,T_c/2$. Further, since there are $2\,Q/N$ slots in the phase-band, replacing q by $2\,Q/N$ gives

$$B_n = \frac{8\,\overline{F}_{\max}}{\pi\,\chi}f_{2Q/N,n}\,\frac{\sin(n\,\chi/2)}{n^2} \quad . \quad . \quad . \quad . \quad (19)$$

---

* S. P. SMITH and R. S. H. BOULDING, *loc. cit.*, Table 3; also B. HAGUE: *Electrician*, 1917, vol. 77, p. 766, Table I.

* It should be noticed in passing that the equation for the phase M.M.F. just proved also holds for the M.M.F. wave of a turbo rotor by making $\omega = 0$ and interpreting q as the number of wound slots per pole.

[illegible] the value of F_{max} from Equation (17) [illegible]

$$F_{max} = \text{[illegible]} \tfrac{1}{2} \text{[illegible]} N = \frac{\text{[illegible]} Q I \text{[illegible]}}{\sqrt{2} N} \quad \text{[illegible]}$$

For closed double-layer windings with two, four, or six equidistant tappings the M.M.F. equation is the same as for single-layer windings with one, two, or three phases and the same phase-spread as we showed in Section 3 II. There is one unique case, namely, the closed winding having three tappings $2\pi/3$ radians apart, which cannot be deduced from the equation derived for a single-layer winding since it is not usual to have such a winding with a phase-spread of $2\pi/3$. For this case the coefficients must be [illegible] at once using the tabulated values* of f_{nQx}, and Equations (19) and (20); and employing the principles laid down in Section 3 II (*d*).

Obviously, the case of the opened double-layer winding follows at once from that of the closed double-layer winding with the same value of σ, as pointed out in Section 3 III.

III. *Illustrative example.*—Having now deduced the form assumed by the Fourier coefficients, B_n, necessary in all cases to take account of the effect of the slots, and having shown that the principles laid down for the deduction of the equation to the M.M.F. wave of a uniformly distributed winding remain valid when the coils are accommodated in slots, we can proceed to illustrate our results by an actual example. As the necessary correction depends on the value of Q, it will be apparent that only specific cases of windings can be considered, and the following illustrative example has been worked out in order to show the method of attacking the problem of finding the equation to the M.M.F. wave of a practical armature winding composed of full-pitch coils carrying sinusoidal phase currents. For this purpose we shall consider in detail the case of the normal three-phase single-layer winding having 3 slots per [illegible]

[illegible] *phase.*—Consider the three-phase single-layer winding for [illegible] copper width occupies one-half the slot-pitch, we shall [illegible]

$$\text{[illegible]}$$

The value of F_{max} found from Equation (17) is

$$F_{max} = \frac{\text{[illegible]}}{\sqrt{2}} \cdot 3 a I$$

Now [illegible] $= a\,Q =$ [illegible], so that $F_{max} = \frac{\text{[illegible]} I}{\sqrt{2}} \cdot \frac{1}{3} = \frac{K}{3}$, since $K = \text{[illegible]} I \sqrt{2}$ so that finally

$$F_{max} = \frac{1\text{[illegible]}}{\text{[illegible]}} \cdot \frac{K}{3} \cdot \text{[illegible]}$$

Following the principles of Section 3 I (*c*) we readily find

$$\begin{aligned} F = \frac{\text{[illegible]}}{\text{[illegible]}} \cdot \frac{K}{3}\Big[& \text{[illegible]} \sin(\theta - \omega t) + \frac{\text{[illegible]}}{5^2} \sin(5\theta + \omega t) \\ & - \frac{\text{[illegible]}}{7^2} \sin(7\theta - \omega t) - \frac{0{\cdot}1450}{11^2} \sin(11\theta + \omega t) \\ & + \frac{\text{[illegible]}}{13^2} \sin(13\theta - \omega t) + \frac{\text{[illegible]}}{17^2} \sin(17\theta + \omega t) \\ & + \frac{\text{[illegible]}}{19^2} \sin(19\theta - \omega t) + \frac{\text{[illegible]}}{23^2} \sin(23\theta + \omega t) \\ & - \frac{\text{[illegible]}}{25^2} \sin(25\theta - \omega t) - \frac{\text{[illegible]}}{29^2} \sin(29\theta + \omega t) \\ & + \frac{\text{[illegible]}}{31^2} \sin(31\theta - \omega t) + \frac{\text{[illegible]}}{35^2} \sin(35\theta + \omega t) \\ & - \frac{0{\cdot}0836}{37^2} \sin(37\theta - \omega t) \ldots \Big] \end{aligned}$$

as the equation to the M.M.F. wave up to the 37th harmonic.

Comparing this equation with Equation (14) we find the following relation between the coefficients, omitting the [illegible] K [illegible]:—

[illegible] harmonic ...	[illegible]	5	7	11	13	17	19	23	25	29	31	35	37
[illegible] distributed	[illegible]	$\frac{18}{5^2}$	$-\frac{18}{7^2}$	$-\frac{18}{11^2}$	$\frac{18}{13^2}$	$\frac{18}{17^2}$	$-\frac{18}{19^2}$	$-\frac{18}{23^2}$	$\frac{18}{25^2}$	$\frac{18}{29^2}$	$-\frac{18}{31^2}$	$-\frac{18}{35^2}$	$\frac{18}{37^2}$
[illegible]	[illegible]	$\frac{\text{[illegible]}}{5^2}$	$-\frac{\text{[illegible]}}{7^2}$	$-\frac{\text{[illegible]}}{11^2}$	$\frac{\text{[illegible]}}{13^2}$	$\frac{200}{17^2}$	$\frac{200}{19^2}$	$\frac{\text{[illegible]}}{23^2}$	$-\frac{\text{[illegible]}}{25^2}$	$-\frac{\text{[illegible]}}{29^2}$	$\frac{19{\cdot}84}{\text{[illegible]}}$	$\frac{18{\cdot}07}{35^2}$	$\frac{18{\cdot}07}{37^2}$
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−11·1	[illegible]	[illegible]	−1·217	[illegible]	−1·004	−1·004

From this tabulation it appears that the general effect of the slotting is to increase the amplitudes of the harmonics over the values obtaining for an unslotted armature with the same phase current and the conductors uniformly distributed. This augmentation of the size of the harmonics is particularly noticeable in the case of harmonics of the order $n = 2uQ \pm 1$, the tooth ripple. Those harmonics for which [illegible] even (e.g. 35th and 37th) have an augmentation only as great as that of the fundamental. The net effect of this change in the relative size of the harmonics is the appearance of the steps upon the M.M.F. wave as is shown in Fig. 12. The shapes shown therein should be compared with those in Fig. 4 for the purpose of obtaining an idea of the effect of the slotting on the peripheral distribution of M.M.F.

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* [illegible]

5. THE EFFECT OF THE COIL-SPAN ON THE SHAPE OF THE M.M.F. WAVE OF A POLYPHASE WINDING CARRYING SINUSOIDAL CURRENTS.

All the preceding sections have been based on the assumption that the armature winding consisted of coils whose span was a full pole-pitch of π radians; but as the coil-span can have values other than this, we must now devote a little attention to the consideration of its effect on the shape of the M.M.F. wave.

It is easy to verify* that in a symmetrical single-layer winding with an even number of phases, the equivalent constant coil-span is $(N-1)/N$ times a full pitch. Another important case is that of a single-layer winding with an odd number of slots per pole-pair, the coil-span being in this instance an odd number of half slot-pitches less than a pole-pitch. Then, again, there is a large class of windings in which the coil-span is shortened by a slot-pitch; such, for example, as the windings proposed by Professor Miles Walker for the armatures of rotary converters. These and many other cases will no doubt occur immediately to the mind of the reader; and so having seen the scope of the problem before us, we must now endeavour to find its solution.

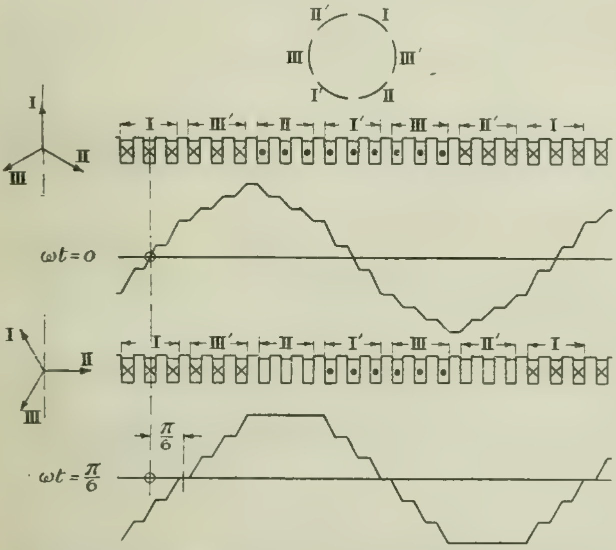

FIG. 12.—The shapes of M.M.F. wave due to a symmetrical 3-phase, single-layer winding with full-pitch coils accommodated in slots (q = 3, Q = 9). Compare with the shapes shown in Fig. 4.

It will be clear that whatever case of short-pitch coils we may consider, much light can be thrown on the problem by investigating the case of a winding consisting of current sheets of angular breadth σ, the pitch of the sheets being less than a pole-pitch by an angular deviation, ϵ. In Fig. 13 (*a*) such current sheets are shown, and for sake of fixing our ideas we may imagine them to be the phase-bands of a short-pitch single-layer winding. The correctness of the various angles represented in the diagram will then be apparent. In Fig. 13 (*b*) current sheets of the same phase-spread and a full-pitch coil span are shown; whilst in Fig. 13 (*c*) the M.M.F. waves for the same current in the coils of both (*a*) and (*b*) are drawn superposed, the difference between the two waves being indicated by the shaded area. Plotting the difference between the waves, Fig. 13 (*d*), shows that the effect of shortening the pitch is to remove an area from the positive half-wave and to add an equal area to the negative half-wave. Assuming the waves in Fig. 13 (*c*) to be of unit height it is easy to prove that the Fourier's series for the difference between them is $a'_0 + \sum_1^\infty a'_n \cos n\theta + \sum_1^\infty b'_n \sin n\theta$ where

$$\left.\begin{aligned} a'_0 &= -\epsilon/\pi \\ a'_n &= -\frac{8(-1)^n}{\pi\sigma n^2}\sin n\frac{\epsilon}{2}\cos n\frac{\epsilon}{2}\sin n\frac{\sigma}{2} \\ &= -\frac{8(-1)^n}{\pi\sigma n^2}\sin n\frac{\sigma}{2} f_{\epsilon,n}\sqrt{(1-f^2_{\epsilon,n})} \\ \text{and } b'_n &= \frac{8(-1)^n}{\pi\sigma n^2}\sin^2 n\frac{\epsilon}{2}\sin n\frac{\sigma}{2} = \frac{8(-1)^n}{\pi\sigma n^2}\sin n\frac{\sigma}{2}(1-f^2_{\epsilon,n}) \end{aligned}\right\} \quad (21)$$

In this series, representing Fig. 13 (*d*), n has all odd and even integral values, and $f_{\epsilon,n} = \cos(n\epsilon/2)$ = the coil-span factor of the nth harmonic.* The origin is at O, the middle of the phase-band.

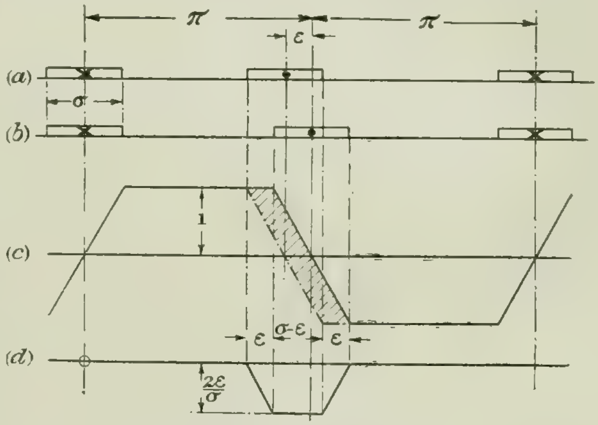

FIG. 13.—The pulsating wave of M.M.F. produced by current sheets of phase-spread σ, and whose pitch is less than a pole-pitch by an angular deviation, ϵ.

(*a*) Current sheets with spread σ and pitch $\pi - \epsilon$.
(*b*) " " " " π.
(*c*) M.M.F. waves produced by the same current in (*a*) and (*b*).
(*d*) Difference between the M.M.F. due to (*a*) and that due to (*b*), (*a*) − (*b*).

Briefly summarized, we see that the effect of altering the coil-span is to superpose on the odd M.M.F. harmonics which would be present with full-pitch coils, other harmonics of odd and even orders derived from Equation (21). Thus, the procedure of finding the M.M.F. equation for a given winding with short-span coils would consist of writing down at once the equation to the wave on the assumption that the coils had a span of a full-pitch and adding thereto the additional harmonics arising out of the value of the angular deviation ϵ. We shall therefore consider these distorting harmonics in greater detail in order to demonstrate the manner of taking them into account.

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* S. P. SMITH, *Journal I.E.E.*, 1917, vol. 55, p. 23.

* See S. P. SMITH and R. S. H. BOULDING, *loc. cit.*

[illegible] 2, the effect of the additional harmonics in the [illegible] take the origin at the middle of the phase-band of Phase I [illegible] Then it will be clear that the M.M.F. of the additional harmonics in the [illegible]

[illegible]

[illegible] reducing to the form given in Equation (21) for a uniformly distributed winding, but having a somewhat different form when slotting is taken into account, as we shall do [illegible]

Then, remembering that $a = 3$ in practice, the M.M.F. of the additional harmonics due to the whole winding is

[illegible]

[illegible]

[illegible]

The effect of the constant term is clearly

[illegible]

[illegible]

[illegible]

Since [illegible] it follows that the pulsating term F_0 vanishes, and hence the M.M.F. wave of a short-span symmetrical winding is symmetrical about the axis of θ, i.e. the positive and negative half-waves are equal in area. They cannot be similar in shape if even harmonics are present.

Two cases arise in dealing with the nth harmonic, namely, when n is odd and when it is even. Considering first the case when n is odd, we have by direct analogy with Equation (5),

(*a*) If n is an odd multiple of N when N is odd, or of N/2 when N/2 is odd:—

$$F_n' = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26a)$$

[illegible]

k is any positive integer.

Hence, the additional odd harmonics introduced by shortening the coil-span are of the same nature as those given by Equation (5), except that each harmonic has a phase angle ζ, proportional to its order. That is, the effect of shortening the coil-span may be looked upon as increasing the value of the odd sine terms which would exist were the coils of full pitch, and providing in addition a complete series of cosine terms of the same odd orders.

Turning to the case when n is even, write $n = 2r$, where r is a positive integer. Then since the numerators of both [illegible] $= \sin (n \pm 1) \pi = 0$, the first or second part only will have finite value if $\sin (n + 1) \beta/2$ or $\sin (n - 1) \beta/2$ is zero respectively. [illegible] leading to $n = k\text{N} - 1$. For the second possibility to be true we shall find $n = k\text{N} + 1$. Hence the existent even harmonics are those of order $n = k\text{N} \pm 1$; and for n to be even it is clear that both N and k must be odd. Applying this to Equation (24) we get for even values of n:—

[illegible]

k is any odd integer in these equations.

From these restrictions, or at once from Equation (24), it follows that

(*c*) If n is an even multiple of N, whether N be odd or [illegible]

[illegible]

We are thus led to classify the different cases which we have considered according to the value of N, as follows :—

(i) In a symmetrical polyphase winding with an even number of phases and short-span coils, the effect of shortening the span is to add to the odd sine harmonics which would be present in the M.M.F. wave if the coils spanned a full pitch, an extra series of sine and cosine harmonics of the same odd orders and linear speeds [c.f. Equations (5*a*) to (5*e*) with (26*a*) to (26*e*)]. Since the M.M.F. wave in such a case contains odd harmonics only it follows that both half-waves will be of similar shape.

(ii) In a symmetrical polyphase winding with an odd number of phases and short-span coils, the effect of shortening the span is to add to the odd sine harmonics which would be present in the M.M.F. wave if the coils spanned a full pitch, an extra series of sine and cosine harmonics of the same odd orders and linear speeds [c.f. Equations (5*a*) to (5*e*) with (26*a*) to (26*e*)], together with a series of sine and cosine terms of all even orders except those for which n is an even multiple of N (Equation 27(*a*)—(*c*)). Since the M.M.F. wave in this case contains even terms, it follows that positive and negative half-waves will be of dissimilar shape.

(*b*) *Simplifications for hemisymmetrical polyphase systems*, $\beta=\pi/N$.—Introducing $\beta=\pi/N$ in Equations (23) and (24) leads us to further interesting results.

Now $\dfrac{\sin(N\beta/2)}{\sin(\beta/2)}=\dfrac{\sin(\pi/2)}{\sin(\pi/2N)}=\dfrac{1}{\sin(\pi/2N)}\not=0$, so that the M.M.F. wave of a short-span hemisymmetrical winding contains a pulsatory term whose value at every part of the periphery is given by

$$F'_0=\frac{F_{\max}\,a'_0}{\sin(\pi/2N)}\cos\left(\omega t-\frac{N-1}{2}\cdot\frac{\pi}{N}\right)$$

$$=\frac{\overline{F}_{\max}\,a'_0}{\sin(\pi/2N)}\sin\left(\omega t+\frac{\pi}{2N}\right)\qquad(28)$$

The positive and negative half-waves will be of unequal area, since owing to this pulsating term, the wave will be unsymmetrically situated about the axis of θ.

Considering, as before, the case when n is odd, we get by comparison of Equations (3) and (24) the following cases corresponding with Equation (6).

(*a*) If n is an odd multiple of N, when N is odd:—

$$F'_n=0\quad.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\quad(29a)$$

(*b*) If $n=2kN-1$, and N is odd or even :—

$$F'_n=(-1)^{kN-n}\tfrac{1}{2}N\,C_n\sin(n\theta+\omega t+\zeta)\quad.\quad(29b)$$

(*c*) If $n=2kN+1$, and N is odd or even :—

$$F'_n=(-1)^{kN-n}\tfrac{1}{2}N\,C_n\sin(n\theta-\omega t+\zeta)\quad.\quad(29c)$$

where k is any positive integer inclusive of zero.

From these equations it appears that the effect of shortening the coil span in a hemisymmetrical winding is to add to the odd sine harmonics which would exist in the M.M.F. wave if the coils had a full span, an additional series of sine and cosine harmonics of precisely the same odd orders.

For the case when n is even the analysis is not so simple, and, referring to Equation (24) let us consider the value assumed by the multiplying factors of the two terms therein when n is an even number and $\beta=\pi/N$. Writing the two expressions in one form, we have

$$\frac{\sin\frac{1}{2}N(n\pm1)\beta}{\sin(n\pm1)\beta/2}=\frac{\sin(n\pm1)\pi/2}{\sin(n\pm1)\pi/2N}=\frac{\pm(-1)^{\frac{1}{2}n}}{\sin(n\pm1)\pi/2N},$$

since $n\pm1$ is odd.

Thus both terms will exist independently of the values of n and N. Furthermore, the factors cannot become infinite, since this would make $(n\pm1)\pi/2N=k\pi$ or $n=2kN\mp1$, which is clearly not an even number. Substituting in Equation (24) we get

(*d*) If n is an even integer and N is odd or even,

$$F'_n=\frac{C_n(-1)^{\frac{1}{2}n}}{2}\left[\frac{1}{\sin(n+1)\pi/2N}\sin\left(n\theta+\omega t-\frac{N-1}{2}(n+1)\frac{\pi}{N}+\zeta\right)\right.$$
$$\left.-\frac{1}{\sin(n-1)\pi/2N}\sin\left(n\theta-\omega t-\frac{N-1}{2}(n-1)\frac{\pi}{N}+\zeta\right)\right]\quad(29d)$$

Hence the even harmonic of the nth order in the M.M.F. wave of a hemisymmetrical winding with short-span coils, consists of two moving waves of unequal amplitudes progressing around the armature periphery in opposite directions at $1/n$th of synchronous speed.

This peculiar and exceedingly interesting result can be viewed from a rather different point of view if we transform Equation (29*d*) in the following way :—

An expression of the form $A\sin\lambda+B\sin\mu$ can be expressed as

$$A\sin\lambda+B\sin\mu=A(\sin\lambda+\sin\mu)-C\sin\mu$$
$$=2A\sin\tfrac{1}{2}(\lambda+\mu)\cos\tfrac{1}{2}(\lambda-\mu)-C\sin\mu,$$

where $C=A-B$. Applying this theorem to Equation (29*d*) gives

$$F'_n=\frac{C_n(-1)^{\frac{1}{2}n}}{\sin(n+1)\pi/2N}\left[\cos\left(\omega t-\frac{N-1}{2}\frac{\pi}{N}\right)\sin\left(n\theta-\frac{N-1}{2}\frac{n\pi}{N}+\zeta\right)\right.$$
$$\left.-\frac{\sin(n\pi/2N)\cos\pi/2N}{\sin(n-1)\pi/2N}\sin\left(n\theta-\omega t-\frac{N-1}{2}(n-1)\frac{\pi}{N}+\zeta\right)\right]$$

Thus we see that the M.M.F. of the nth harmonic of even order can be conceived as consisting of two separate parts, as follows :—

(i) A pulsating sine wave of wave-length $2Y/n$ whose period is that of the current in the winding, $T=1/f=2\pi/\omega$; and

(ii) A pure rotating wave of wave-length $2Y/n$ moving at $1/n$th of synchronous speed in the same direction as the fundamental.

It is interesting to note, in passing, the following peculiarities of the even harmonics in the M.M.F. wave of a hemisymmetrical two-phase winding with short-span coils. Since $\sin(n\pi/2N)=\sin(n\pi/4)=0$ when n is an even multiple of 2, it follows that the 4th, 8th, 12th, etc., harmonics are purely pulsating waves.

II. *Determination of c'_n and ζ for uniformly distributed windings.*—Having now worked out the general effect on the M.M.F. wave of a winding consequent upon altering the coil-span, we must turn to the evaluation of c'_n and ζ before we can calculate an actual example. For this

[illegible]

[illegible]

$$[illegible]$$

[illegible] *of phases.*—We have pointed out that the coil-span in such [illegible]

$$[illegible]$$

Remembering that no even harmonic can exist in the [illegible] quantities for four-phase and six-phase windings [illegible]

that all the slots were wound with coils, but in the present instance that assumption may or may not be true, since a short coil-span is often obtained in practice by the use of empty slots. In order to cover this possibility, let q_0 be the number of wound slots in the phase-band; then it will be clear that the additional harmonics introduced into the M.M.F. wave by shortening the span will be for the sth coil of the first phase,

$$[illegible]$$

this expression following at once from Equations (22) and (30). By the method of Section 4, summing this expression for the total number q_0 of coils in the phase-band and referring the wave to the middle of the phase-band where [illegible], gives

$$\text{M.M.F. wave of first phase} = -\frac{F_{\max}\,\epsilon}{[illegible]}\cos\omega t$$

$$[illegible]$$

similar to an equation in Section 4.

TABLE 4.

[illegible] and Coil-span = [illegible] (N − 1) N.

	[illegible]					[illegible]		
[illegible]	[illegible]	[illegible]	$\sqrt{(1-C_p^2)}$	[illegible]	[illegible]	[illegible]	$\sqrt{(1-C_p^2)}$	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	−3π/8	[illegible]	0·9659	[illegible]	−5π/12
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	π/4	[illegible]	[illegible]	−π/4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−π/12
7	7π/8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	π/12
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	π/4
11	[illegible]	[illegible]	[illegible]	7π/8	[illegible]	[illegible]	0·2588	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	13π/12	[illegible]	[illegible]	7π/12
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−0·7071	−0·7071	3π/4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−0·2588	−0·9659	11π/12
[illegible]	[illegible]	[illegible]	0·9230	[illegible]	[illegible]	0·2588	[illegible]	13π/12
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−0·7071	5π/4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23π/12	[illegible]	−0·2588	17π/12

[illegible] are, in the nature of things, dependent [illegible] an arbitrary value for ε. That this must [illegible] will be obvious when we remember that all the other [illegible] which we have mentioned involve reference to the [illegible] pitch, a term which has clearly no meaning in a winding [illegible] We must [illegible] [illegible]ntrated in slots. The value of ε is then [illegible]

III. [illegible]—The effect of concentrating [illegible] In that section we assumed [illegible]

[illegible]

and

$$[illegible]$$

analogous to Equation (18). Also from obvious considerations,

$$[illegible]$$

The value of $F_{\max}$ is conveniently calculated for single-layer windings from Equation (17) and for double-layer windings from Equation (20).

Owing to the specific nature assumed by our problem we can now do no more than point out the various values attained by ε in the cases arising in practice.

(i) *Single-layer winding with a even number of phases and a symmetrical system of currents.*—We have just considered the values of ε and ζ in this case when dealing with uniformly distributed windings in the preceding subsection and so need not discuss the matter here. Suffice it to point out that Equation (31) must of course be used, remembering that it is common practice to wind the whole of the slots in such a winding, so that $q_0 = q = Q/N$.

(ii) *Single-layer winding with an odd number of slots per pole-pair.*—If the number of slots per pole-pair in a machine be odd it will be clear that the number of slots per pole, Q, will be an integer $+\frac{1}{2}$. Hence if the coil-span be Q_0 slot-pitches, we have since $Q\gamma = \pi$, $\varepsilon = \pi - Q_0\gamma = (Q - Q_0)\gamma =$ an odd number of half-slot-pitches $= x\gamma/2$, where x is odd. Thus,

$$f_{\varepsilon,n} = \cos(n x \gamma/4) = \cos(n x \pi/4Q) \text{ ; and } \zeta = [(n x/2Q) - 1]\tfrac{1}{2}\pi$$

It will be obvious that $f_{\varepsilon,n}$ vanishes for values of n which are odd multiples of 2 Q, and becomes equal to ± 1 for even multiples. Now, since $\sqrt{(1 - f^2_{\varepsilon,n})} = \sin(n\varepsilon/2)$ it follows that $C_n = 0$ when $f_{\varepsilon,n} = \pm 1$, and so in any case in which it is possible for the shortening of the coil-span to introduce even harmonics into the M.M.F. wave, those even terms whose order is an even multiple of 2 Q will vanish from the wave.

(iii) *A winding with the coil-span equal to* $\pi - \gamma$.—The case of a winding in which the coil-span is a slot-pitch less than a pole-pitch arises fairly frequently in practice in such examples as the "mush" winding and the closed commutator windings used for rotary converters. For such cases, $\varepsilon = \gamma$ and therefore $f_{\varepsilon,n} = \cos(n\gamma/2) = \cos(n\pi/2Q)$ and $\zeta = [(n/Q) - 1]\frac{1}{2}\pi$.

We should note, in passing, the following point in connection with the application of our results to commutator windings. In these windings it very frequently happens that the double coil-span is less than 2π; but we can always group the coil-sides so as to form equivalent coils like the one shown in Fig. 13, and it is to such equivalent coils that our analysis applies.

It will also be clear that the case of a lengthened coil-span is covered by all our results by changing the sign of ε throughout.

IV. *Illustrative examples of the effect of altering the coil-span.*—With the aid of the various theorems which we have just proved, it is easy to discuss the effect which shortening the coil-span has upon the harmonics present in the M.M.F. wave. In order, therefore, further to emphasize the technical importance of the coil-span, we shall examine in greater detail certain aspects of the problem which require special notice.

First, let us consider the case of a single-layer winding with an even number of phases; then, as pointed out above, $\varepsilon = \pi/N$ and the phase-spread $\sigma = \pi/N$ also. Referring to Section 5 I (*a*) i, we see that no even harmonics are present in the M.M.F. wave of such a winding when supplied with a symmetrical system of currents. The odd harmonics present are those of order $n = 2kN \pm 1$ together with those for which $n = kN \pm 1$. Considering the former as the general type and following the methods of the present section, we have, by first assuming that the coil-span was a full-pitch,

$$F_n = \tfrac{1}{2} N B_n \sin(n\theta \mp \omega t) \qquad \text{(Sect. 2 II } a\text{, Equations } 5b, 5c)$$

When the coils are of short-pitch the additional harmonics are,

$$F'_n = \tfrac{1}{2} N C_n \sin(n\theta \mp \omega t + \zeta) \qquad \text{(Sect. 5 I } (a)\text{, Eq. } 26b, 26c)$$

of the same odd orders; so that the M.M.F. of the nth harmonic is for the short-span winding :—

$$F''_n = F_n + F'_n = \tfrac{1}{2} N [B_n \sin(n\theta \mp \omega t) + C_n \sin(n\theta \mp \omega t + \zeta)]$$

referred to the middle of the phase-band of Phase I as origin.

Now in the present case,

$$\zeta = [(n/N) - 1]\tfrac{1}{2}\pi \qquad \text{(Sects. 5 II (i), 5 III (i))}$$

so that

$$F''_n = \tfrac{1}{2} N \left\{ B_n \sin(n\theta \mp \omega t) + C_n \sin[n(\theta + \pi/2N) \mp \omega t - \pi/2] \right\}$$

The phase-spread is π/N. Changing the origin to the beginning of Phase I by writing $\theta = \theta' - (\pi/2N)$ gives

$$F''_n = \frac{N}{2}\left[B_n \sin\left(n\theta' \mp \omega t - \frac{n\pi}{2N}\right) + C_n \sin\left(n\theta' \mp \omega t - \frac{\pi}{2}\right)\right]$$

$$= \frac{N}{2}\left[B_n \sin(n\theta' \mp \omega t)\cos\frac{n\pi}{2N} \right.$$
$$\left. - B_n \cos(n\theta' \mp \omega t)\sin\frac{n\pi}{2N} - C_n \cos(n\theta \mp \omega t)\right]$$

If we now compare Equation (7) with Equation (30), or (18) with (31*a*), we shall find

$$C_n = (-1)^n \sqrt{(1 - f^2_{\varepsilon,n})}\, B_n = -\sin n\frac{\varepsilon}{2} B_n = -B_n \sin\frac{n\pi}{2N}$$

since in the present case $\varepsilon = \pi/N$ and n is only odd. Hence, with reference to the new origin,

$$F''_n = \tfrac{1}{2} N B_n \sin(n\theta \mp \omega t)\cos(n\pi/2N)$$
$$= \tfrac{1}{2} N B_n f_{\varepsilon,n} \sin(n\theta' \mp \omega t) = \tfrac{1}{2} N B''_n \sin(n\theta \mp \omega t)$$

a form precisely similar to that obtained for full-pitch coils, B''_n replacing B_n.

Assuming for the present that the winding is uniformly distributed,* we have $B_n = (8/\pi\sigma n^2)\sin(n\sigma/2)$, so that

$$B''_n = B_n \cos\frac{n\pi}{2N} = \frac{8N}{\pi^2 n^2}\sin\frac{n\pi}{2N}\cos\frac{n\pi}{2N} = \frac{4N}{\pi^2 n^2}\sin\frac{n\pi}{N}$$

since $\sigma = \pi/N$.

Now if the coils were actually of full-pitch and σ was $2\pi/N$, the value of the Fourier coefficients would be $B_n = (4N/\pi^2 n^2)\sin(n\pi/N)$, which is identical with that just found for the chorded winding. Hence it follows that the shapes of the M.M.F. wave in the two cases are the same at every instant, except that there is a space lag of $\pi/2N$ in those of the short-pitch winding.

Thus, in order to write out the equation to the M.M.F. wave of a single-layer winding with an even number of phases, $\sigma = \pi/N$, and $\varepsilon = \pi/N$, first write down that of a winding with full-pitch coils, the same number of phases, and $\sigma = 2\pi/N$ from the results proved in earlier sections of the paper and then change θ therein to $\theta + (\pi/2N)$.

---

* Corresponding results are readily found for slotted armatures by following the same method.

[illegible] commutation Professor Miles Walker has proposed the [illegible] the number of phases is even, there will only be odd terms in the series expressing the M.M.F. wave, and their [illegible] shown.

[illegible]

[illegible] being found at once for those of order $n = 6k \pm 1$ from [illegible]

[illegible]

[illegible] Hence (except for those harmonics which have the same [illegible] of the harmonics in the M.M.F. wave are relatively less compared with the fundamental when the coil-span is shortened by one slot-pitch then when the coil-span is equal to a full-pitch. The result of this is that the shapes [illegible]

[illegible] wave of magnetomotive force contains even [illegible] tance of this fact is particularly great in [illegible] example if we have an alternator with a three-phase double- [illegible] coils, it is [illegible]

currents will contain even harmonics; and the resultant of this field and that of the main poles will therefore contain such harmonics also. This being so, the pressure wave induced on load will contain even terms, the presence of which has been noticed by some observers, though the reason for their existence has not been pointed out.

With a hemisymmetrical short-pitch winding there is in addition to even harmonics a pulsating field of uniform value around the periphery. Thus in a two-phase induction motor whose stator has a short-pitch winding, we may expect the pressure induced in the rotor winding to consist of terms derived from the odd and even gliding fields, and superposed thereon an electromotive force induced by mutual induction between the pulsating part of the stator field and the rotor winding.

6. The Effect of Non-sinusoidal Currents on the Shape of the M.M.F. Wave.

We have assumed in all our preceding work that the phase currents followed a cosine law. However, sinusoidal current wave-forms are rarely obtained in practice, due principally to the effects of magnetic saturation and hysteresis*; i.e. to the cyclically varying permeability of the iron circuit linked with the windings. Thus, for example, the stator current taken by an induction motor supplied with a sine pressure at its terminals will differ very materially from a sine shape. We shall therefore make it our object to discuss in the present section some of the effects which harmonics in the phase current may have upon the magnetomotive force of a winding; and for this purpose we shall use the most general expressions in order to cover the case of a winding with coils of any given arbitrary pitch.

Let us suppose that the phase-current wave has been resolved into a Fourier series of cosines, which for the first phase will be :—

[illegible]

where n' is the order of a current harmonic and is odd, since current waves are as a rule symmetrical about the time axis. Then if we investigate the M.M.F. wave due to the n'th current harmonic in the manner employed for the fundamental in previous sections, the following results arise. Since the space distribution of the M.M.F. of a phase depends only on the phase-spread and the arrangement of the conductors, we easily find that the general expression for the pulsating M.M.F. wave of the mth phase due to the n'th current harmonic is :—

[illegible]

where, in general, n has all odd and even values, and b_n [illegible] as well as those due to the shortened coil-span.

By summing this expression for the N phases we get as the equation to the M.M.F. wave due to the n'th current harmonic,

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* [illegible]

$$F_{n'} = \sum_{m=1}^{m=N} F_{n',m} = F_{n'\,\max} \sum_{m=1}^{m=N} \Big[\cos\{n'[\omega t-(m-1)\beta]-\phi_{n'}\}\{a'_0+\sum_1^{\infty} a'_n \cos n[\theta-(m-1)\beta]+\sum_1^{\infty} b'_n \sin n[\theta-(m-1)\beta]\}\Big]$$

The pulsating term gives at once

$$F_{n',0} = \bar{F}_{n',\max}\, a'_0 \cos[n'\omega t - \phi_{n'} - \tfrac{1}{2}(N-1)\beta]\frac{\sin\frac{1}{2}N\beta}{\sin\frac{1}{2}\beta}$$

analogous to Equation (23).

Likewise, selecting the nth harmonic of the wave gives

$$F_{n',n} = \bar{F}_{n',\max}\, a'_n \sum_{m=1}^{m=N} \cos\{n'[\omega t-(m-1)\beta]-\phi_{n'}\} \cos n[\theta-(m-1)\beta] + \bar{F}_{n',\max}\, b'_n \sum_{m=1}^{m=N} \cos\{n'[\omega t-(m-1)\beta]-\phi_{n'}\} \sin n[\theta-(m-1)\beta]$$

which becomes on simplification,

$$\begin{aligned} F_{n',n} &= \frac{A'_{n',n}}{2}\Big[\cos\{n\theta+n'\omega t-\frac{N-1}{2}(n+n')\beta-\phi_{n'}\}\frac{\sin\frac{1}{2}N(n+n')\beta}{\sin\frac{1}{2}(n+n')\beta} \\ &\quad +\cos\{n\theta-n'\omega t-\frac{N-1}{2}(n-n')\beta+\phi_{n'}\}\frac{\sin\frac{1}{2}N(n-n')\beta}{\sin\frac{1}{2}(n-n')\beta}\Big] \\ &\quad +\frac{B''_{n',n}}{2}\Big[\sin\{n\theta+n'\omega t-\frac{N-1}{2}(n+n')\beta-\phi_{n'}\}\frac{\sin\frac{1}{2}N(n+n')\beta}{\sin\frac{1}{2}(n+n')\beta} \\ &\quad +\sin\{n\theta-n'\omega t-\frac{N-1}{2}(n-n')\beta+\phi_{n'}\}\frac{\sin\frac{1}{2}N(n-n')\beta}{\sin\frac{1}{2}(n-n')\beta}\Big] \qquad (32) \end{aligned}$$

which is similar in form to Equations (3) and (24). Comparison of the two equations will show that all the theorems deduced from Equations (3) and (24) can be immediately transformed for the present case by writing in them $n'\omega t-\phi_{n'}$ for ωt and augmenting the values of n for which they are deduced by $n'-1$.

It is thus clear that the M.M.F. of the winding due to all current harmonics is $F=\sum_{n'=1}\Big[F_{n',0}+\sum_{n=1}^{n=\infty}F_{n',n}\Big]$, where the first summation applies to all the harmonics into which the current wave has been resolved, and the second summation covers such odd and even space harmonics as previously proved theorems have shown to be existent in the M.M.F. wave.

We thus see that the expression for the nth gliding field of M.M.F. due to the n'th current harmonic can be written in the general form,

$$V \begin{matrix}\cos\\ \sin\end{matrix}\{n\theta \mp n'\omega t - \psi_{n',n}\}$$

Now $T_{n'} = 1/f_{n'} = 1/nf = 2\pi/n'\omega$ is the periodic time of the n'th current harmonic, and $\lambda_n = 2\pi/n =$ the angular wave-length of the nth space harmonic; hence the angular velocity of the nth gliding field produced by the n'th current is, $\omega_{n',n} = \lambda_n/T_{n'} = n'\omega/n$. Now the angular velocity of the nth constituent field due to the fundamental current is ω/n; and so corresponding space harmonics move n' times as quickly when they are produced by the nth harmonic in the current as they do when produced by the fundamental.

Without using further mathematics all the properties of the wave of M.M.F. produced by any current harmonic can be easily found from a consideration of the vector diagram of phase currents. In a symmetrical N-phase system, the vector of the n'th current harmonic in the mth phase is displaced from that in the first phase by an angle $(m-1)\,n'\,2\pi/N$, and according to the value assumed by this angle it can be shown* that the nth harmonic diagram will fall into one of three classes which may be briefly summarized in the following way :—

(i) in which the vectors in the n'th harmonic diagram are numbered in the same direction around the diagram as the vectors for the fundamental ;
(ii) in which the vectors in the n'th harmonic diagram are numbered in the reverse direction around the diagram to the vectors for the fundamental ; and
(iii) in which the vectors in the n'th harmonic diagram form coincident groups.

For example, in a three-phase system the 7th 13th, 19th, etc., harmonics fall into the first class ; the 5th, 11th, 17th, etc., harmonics into the second ; whilst the 3rd, 9th, 15th, etc., harmonics form the third type.

For harmonics falling into the first class it is clear that the equations to the M.M.F. wave produced by them can be found at once from that of the fundamental by changing ωt to $n'\omega t-\phi_{n'}$ therein. Hence harmonics of this class in the current wave produce identically the same shape of M.M.F. wave as the fundamental current, except that the waves move n' times as quickly.

Likewise the equations corresponding to harmonics in the second class are found by changing ωt to $-n'\omega t-\phi_{n'}$ since the currents of these orders in successive phases attain their maxima in the reverse order to the fundamentals. Hence, harmonics of this class in the current wave produce identically the same shape of M.M.F. wave as the fundamental current, except that the waves move n' times as quickly in the opposite direction.

In the third class are those harmonics which are an odd multiple of the number of phases (when N is odd) or of half the number of phases (when N/2 is odd). The vector diagrams in the former case consist of N coincident vectors ; whilst in the latter case there are two groups of N/2 vectors displaced from each by π radians. Taking the case when N is odd, let us consider the form assumed by Equation (32) when $\beta=2\pi/N$. Since in this case $\sin\frac{1}{2}N(n\pm n'/\beta=0$, every term of the equation vanishes unless it happens that $\sin(n+n')\frac{1}{2}\beta$ or $\sin(n-n')\frac{1}{2}\beta$ is zero. Now when N is odd, the harmonics which we are now considering are of order $n'=kN$, k being odd ; hence $\sin(n\pm n')\frac{1}{2}\beta=\sin(n\pm kN)\pi/N=-\sin n\pi/N$ will be zero if n/N is an integer, say s. Thus if $n=sN$ all the terms of Equation (34) will persist. A like result will hold when N is even and N/2 odd if $n=sN/2$. Now the successive pairs of terms in the equation are gliding fields moving at equal speeds in opposite directions, and by Ferrari's principle will combine to form a standing wave. Thus it follows that the magnetomotive force of a current

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* B. HAGUE : *Electrician*, *loc. cit.*

[illegible] the third case is a standing wave whose wave-length is [illegible] N when N is odd, or [illegible] N when N is even, and which pulsates in value at n' times synchronous frequency. For example, in the case of a three-phase winding such as is commonly employed in induction motors, a single-frequency current will produce a pulsating wave of M.M.F. represented in the form of a triangular wave of wave-length [illegible], the frequency of pulsation being [illegible] times normal frequency.

CONCLUSION.

The foregoing investigation constitutes, in the author's belief, the first attempt at a complete analytical treatment of the magnetomotive force of an armature winding, and it is hoped that the results set out and the methods developed will prove useful in the investigation of problems connected with the theory and action of electrical machines. It was mentioned earlier that in spite of much excellent work many such problems are still far from solved, and it is to some of these problems that the author intends to devote his attention in a subsequent communication.

Finally, the author desires to thank Dr. S. P. Smith for his kindness in reading the manuscript and for giving many useful suggestions. Indebtedness to many friends for kindly criticism must be recorded; and the author particularly offers his gratitude to Mr. S. Neville, B.Sc., without whose friendly help and inspiring suggestions much of the work involved in the paper could hardly have been accomplished.

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THE MAGNETIC SHIELDING OF LARGE SPACES.*

By Professor ERNEST WILSON, Member.

[illegible] MANCHESTER LOCAL SECTION [illegible]

The investigation now to be described has been carried out in collaboration with my colleague Professor Nicholson, in the Siemens Electrical Engineering Laboratory, King's College, London, and some of the main results are embodied in papers recently presented to the Royal Society. All previous work on magnetic shielding, in which a large shielding ratio has been obtained, has referred to very small spaces, and as large spaces present a very different type of problem, it will not be necessary as a preliminary to give any account of such work.

The effective shielding of a large space, which has become necessary for some important practical applications, constitutes a new fundamental problem. It is easily realized that for this purpose a spherical shield is, on general grounds, the most efficient form, but it is necessary at the same time to laminate it into several component spherical shells with a common centre. Lamination, however, cannot be carried with advantage beyond a certain limit. Rücker found that for a given total mass of iron the use of two shields was not an advantage if they were made too thin. We have extended this investigation, and it appears that there is always a critical thickness beyond which lamination must not be carried. Without going into details it may be said that the most [illegible] the air spaces and thicknesses are very nearly the same, and in the shield designed on this principle it adopted. The air spaces and thicknesses (2 cm.) are about 4 times the critical values which the theory indicates.

The theory of a single spherical shield is well known. It culminates in Maxwell's formula for the shielding ratio—

$$[illegible]$$

where F is the outside force, μ the permeability, and a, b the inner and outer radii respectively of the shell.

Before proceeding to the description of any definite experiment on shielding, it is desirable to give some account of what is meant by initial permeability, which is, from one point of view, the decisive factor in the efficiency of a magnetic shield.

The early experiments of Baur and Rayleigh showed that the initial permeability of iron has a finite value when the magnetizing force is very small, and the curve of magnetization is practically a straight line in this region. This is the permeability referred to in the Maxwell equation. At a later stage as the force is increased the curve becomes more parabolic. Baur's experiment on [illegible] showed that within the limits of force $H =$ [illegible] and $H =$ 0·384 the formula $\mu =$ [illegible] H is applicable, and in this formula the initial permeability is 183. The experiments of Lord Rayleigh confirmed this result.

It is not possible to refer in detail to the work which has been done on this subject, but it may be mentioned for purposes of illustration that a 3 per cent silicon-iron alloy (Stalloy) gives a permeability of 260 after careful demagnetization. The same alloy can be made to give an initial permeability of 427 if demagnetized when moderately shielded from the effect of the earth's magnetic field. The reason for this increase will be dealt with later, but before resuming the consideration of the problem of shielding it may be stated that one of the main uses to which shielding can be put, and the foundation of its more important practical applications, is this increase in permeability in shielded material.

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* [illegible]

We can prove that a single shell of unlimited thickness, according to Maxwell's formula, can give only a shielding ratio of 22 when the permeability is of the order of 100. This is quite insufficient for many purposes, and if higher degrees of shielding are to be obtained it is necessary to resort to lamination of the shield. This important fact has been realized since Sir William Christie protected the magnetic instruments at Greenwich in 1893 by the use of a triple shield. Even with lamination it may be stated, however, that for a given shielding ratio the amount of iron required may become prohibitive. It is therefore necessary to study the fundamental principles involved in order that for a given volume of the enclosed space and a given shielding ratio the weight of iron may be a minimum. The late Sir Arthur Rücker stated the conditions which are necessary in certain cases in order that increased lamination may continue to be advantageous. One of these, the critical thickness, has already been mentioned. As a generalization of his work it may be shown that the degree of shielding depends mainly upon the curvatures of the surfaces of the shield. For example, if we compare two shields of the same material whose linear dimensions are to one another as $1/n$, the shielding ratios will be the same, that is, they are independent of the absolute dimensions. The shield presently to be described consists of four spherical shells each of thickness 2 cm. with intervening air spaces of the same dimensions, and the outer diameter of the outermost shell is 3 feet. A shield similar in every respect whose outside diameter is the same as that of the earth will give precisely the same shielding ratio provided that instead of 2 cm. the thicknesses of each of the shells and air spaces is 179 miles.

Rücker showed that for a permeability of 500 there is no "best arrangement" in the case of two shells unless the volume of the material of the shells exceeds about 1/100 of the volume of the enclosed space. It can be shown that if the permeability is 100 the volume must not exceed 1/20 of the space to be shielded. That is to say there is no advantage to be gained from lamination unless the thickness of the shell is greater than $3/2\ \mu$ of its radius. This work for equal permeability has been extended to the case of three shells with the same result as regards limiting thickness. As it is an advantage in the case of large shells to have equality of thickness it is important to notice that if the shells have equal thickness, with air spaces in correspondence, no great sacrifice is made.

In connection with certain work, it was desired to obtain a shielding ratio of 0·002, the enclosed space being spherical and of diameter 63·5 cm. (25 inches). If the permeability is 100 the thickness of each shell must be greater than ½ cm., and some multiple of this had to be chosen. It was decided to adopt a thickness of 2 cm., because this made the castings an engineering possibility, and the air spaces were also 2 cm. The shells of high permeability dynamo-magnet steel made to this specification by Messrs. Edgar Allen & Co. are quite satisfactory, and have proved to have an initial permeability of about 150. The weight of the whole shield is 1,273 kg. (2,806 lb.).

It is not proposed to give here a full account of the somewhat complicated mathematical investigation which is necessary in order to determine the shielding ratio given by a set of spherical shells. A brief indication of the nature of the method will be sufficient. In the following calculations of the shielding ratios of the above shells use has been made of recurrence formulæ, as the Rücker expression as a determinant for the shielding ratio does not lend itself to rapid calculation. Perhaps a small digression may be made at this point in order to indicate what is meant by recurrence formulæ. Suppose that it is necessary to calculate, successively, a set of n quantities, which may be called

$$a_1\, a_2\, a_3\, a_4\ \ldots\ a_n,$$

where the first is known. We may be able to find a connection between any two; for example if the rth and the $r+1$th are connected by

$$a_{r+1} = (r^2 + r)\,a_r,$$

then

$$\begin{aligned} a_2 &= (1^2 + 1)\,a_1 \\ a_3 &= (2^2 + 2)\,a_2 \\ a_4 &= (3^2 + 3)\,a_3, \text{ etc.,} \end{aligned}$$

and each can be calculated at once from its predecessor. This is the basis of the method we adopted in our calculations. The work was, in fact, rather more complicated in that we had two sets of quantities,

$$u_1\, u_2\ \ldots$$

and

$$v_1\, v_2\ \ldots$$

and were able to calculate the ratios

$$u_2/u_1,\ u_3/u_1,\ \ldots \text{ and } v_2/u_1,\ v_3/u_1,\ \ldots$$

and if there are n shells, the shielding ratio for any r of them measured outwards was merely

$$\frac{1}{3}\left(\frac{v_{r+1}}{u_1}\right) + \frac{2}{3}\left(\frac{u_{r+1}}{u_1}\right)$$

so that the effect of an additional shell on the outside could be determined at once. The ratios obtained for 1, 2, 3, and 4 shells are given in Table 1, and it will be seen that they do not deviate much from a geometrical progression. In our experimental shield, every new shell added makes the shield more than twice as efficient.

TABLE 1.

Permeability		100	150	200	300	400
Ratio	No of Shells					
$(v_2+2u_2)/3u_1$	1	4·33	6·03	7·9	10·9	14
$(v_3+2u_3)/3u_1$	2	9·88	15·4	21	34·4	55
$(v_4+2u_4)/3u_1$	3	20·13	34·8	54	103·9	199
$(v_5+2u_5)/3u_1$	4	40·1	69·3	133	313	719

[illegible] halved for every new shell added to the combination when the permeability is of the order 100, and more than halved [illegible] magnet steel used. It will be noticed how rapidly the ratio increases with the permeability. Thus the ratio of [illegible] for four shells and one shell is 51·3 when the [illegible]

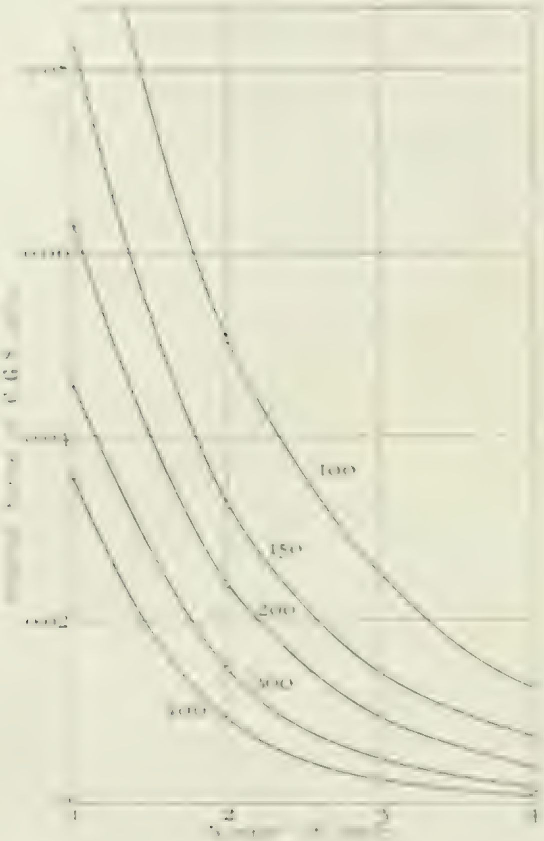

FIG. 1.

[illegible]

[illegible] tion with wound coils, as it was necessary to know the magnetic induction (B) at any point in the system produced by a current in a winding on one of the shells. It was also necessary to test the accuracy of the Maxwell [illegible] manner that the plane of its windings is at right angles [illegible] t. Then if the coils are indefinitely [illegible] th of the field inside the winding [illegible] value $8\pi n i/3$; where the total [illegible] i the current. In the experiments made with spherical shells the numbers of turns commencing with the smallest shell are 34, 38, 42, 46, and the value of n is $\frac{1}{2}$. In other words, the pitch of the winding is 2 cm., which is also the radial thickness of each shell. We cannot expect under these circumstances to find that experiment will give a value of the maximum magnetic induction ($B_{max.}$) so high as is predicted by the theory, on account of looseness of winding, and this has been found to be the case.

When a shell of iron is wound with a coil as above described the magnetic induction (B) is not of course constant throughout its mass. It has a minimum value near the poles or intersections of the shell and the axial diameter. The maximum value occurs in the iron normal to the plane which contains the centre of the shell and is at right angles to the axial diameter. The theoretical treatment is not dealt with here, but the values of $B_{max.}$ for various combinations have been calculated and the results are given in Table 2. The shells are numbered from inner to outer, and the third shell is chosen as a unit when the coil is wound on the inner surface. The other figures show the multiple of this unit in different combinations for the same current. Certain of these figures have been verified by experiment, which shows that they are, under the conditions of winding, a small percentage too high. The values of $B_{max.}$ can be found from the above figures, if it is remembered that a current of i amperes in the magnetizing coil produces a value of $B_{max.}$ of 5·9 in the third shell taken as a unit. Of course this only refers to the case of small currents, that is to say, such currents as produce permeability not greatly differing from its initial value. For example, with the combination of four shells, and a coil wound on the outside of the fourth shell, the calculated value of $B_{max.}$ in the third shell is slightly high with 2·5 amperes; and the value for the fourth shell is slightly high with about 1 ampere.

TABLE 2.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
1	—	—	[illegible]	—·45	—0·06
2	—	—	—	—1·38	—0·17
3	+1	—2	—0·38	—4·14	—0·42
4	—	—	+4·71	+5·52	—1·26

EXPERIMENTAL.

The shield with the upper half removed is shown in Fig. 2. For the measurement of the force inside the shield an inductor ring rotated by hand has been used in conjunction with a ballistic galvanometer. The diameter of the inductor is such that it just clears the iron of the smallest shell. One end of the winding is connected to a sector on the shaft and brush which makes contact during one half revolution, the other end being connected to a [illegible] contact. The brushes are supported by a disc which is capable of being turned through known angles. At a speed of about $\frac{1}{3}$ to $\frac{1}{2}$ second per revolution it has been found possible to close a key in the circuit of the inductor and galvanometer by hand, and thus impress upon the instrument the electromotive force developed during a half revolution. In this way the direction as well as the magnitude of the force has been measured. The maximum sensibility is such that a force of 10^{-4} that of the earth can be measured with some accuracy. The axis of rotation is in all cases in the plane of the junction of the shell or shells.

The observed deflection is thus a measure of the average magnetic intensity over the volume swept by the inductor. In the diagrams the curves show the relation between the average magnetic intensity and the position of the brushes. When the plane of the coil of the inductor is vertical the inclination is 0° at the moment contact is made and broken during the one half revolution which causes the deflection. At 90° the coil is horizontal, and the direction of the earth's field is at about 67°. The forces above the axis of abscissæ are positive, that is of the same sign as the earth's field.

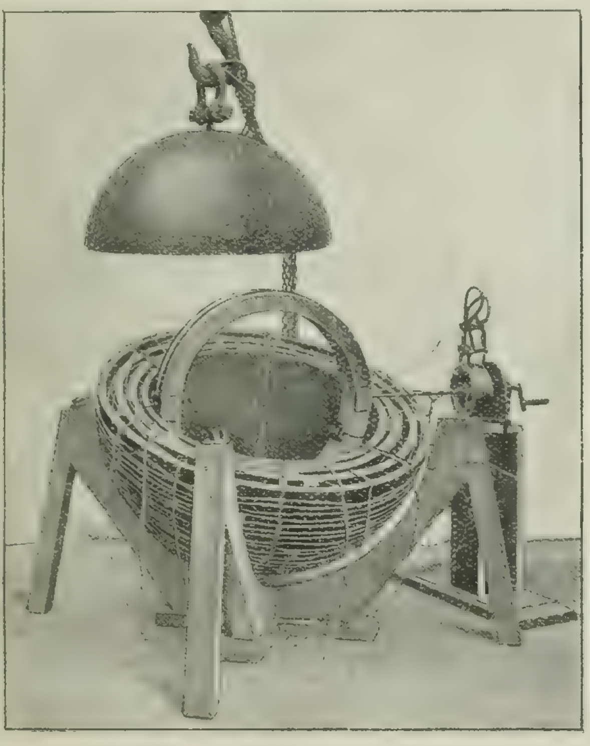

FIG. 2.

Experiments have been made with the shells as received from the foundry with plain butted unmachined surfaces in contact, and also after they had been so machined that one half of each shell enters the other half to the extent of 1 cm. The curves shown in Fig. 3 were obtained when the shells were in the former condition and the planes of junction were horizontal. The axis of the inductor was at right angles to the magnetic meridian. Curve 1 was obtained by rotation of the inductor inside the first or smallest shell alone; curve 2 when the second shell was placed concentrically with the first; and so on to curve 4, when the four shells were all present. The effect of having the junctions in a horizontal plane is marked, since the maximum ordinates of curves 1, 2, 3, occur at 90° instead of at 67° (the direction of the earth's field). Moreover, curves 1, 2, 3, are far from representing sine functions of the angle, mainly because leakage occurs at the junctions. With three shells in combination, however, a new factor begins to exert itself, and this is dealt with below.

The most interesting feature of Fig. 3 is the reversal of sign shown by curve 4; and several experiments resulting in curves, *b*, *c*, *d*, *e*, were made to elucidate its origin. In these experiments the four shells were still present, and their junction planes were varied in position relatively to the direction of the earth's field and to one another. It is obvious from their sign that none of these curves can represent the shielded force of the earth. Moreover, even if the forces had had the right sign, their magnitudes do not agree with the theoretical values given in Table 1; for with four shells and a permeability of 150 an internal force of 0·007 C.G.S. units is indicated; whereas the measured forces are of the order 0·02 C.G.S. units. The fact is that iron does not behave in the ideal manner indicated by the theory; or in other words the shielding ratio does not necessarily continue to rise as more and more shells are added. Apart from the magnetic leakage due to the discontinuity of the metal at the planes of junctions, the behaviour of the iron is dependent upon the permanent polarizing effect of the earth's field on the material. When the shells are few in number, the fields due to this cause are not relatively serious; but they at once become important when the shielding ratio is sufficiently high, and therefore the fields to be examined are sufficiently small, as is the case with four or more shells. It becomes a question as to what is meant by effective demagnetization; and further experiments show that there is a limit beyond which permanent polarization cannot be removed merely by reversal and diminution of currents in the coils wound on the shells. It is shown that in order completely to demagnetize the iron it must during the application of the demagnetizing current be shielded from all steady magnetic fields, of which that of the earth is a particular example. In order to show that this disturbing force cannot be eliminated by demagnetization in the presence of the earth's field, the four shells after being machined were placed with their junction planes at right angles to the direction of the earth's field and carefully demagnetized by connecting the coils wound on Nos. 1, 2, 3, in series, so as to give alternating signs to their forces, and passing an initial current of 4·7 amperes through them. This current was gradually reduced by stages, and at each stage a number of reversals made, until the final value of the current was 0·00006 ampere. The interior force was then measured by the inductor and found to be negative in sign and of value 0·0038 C.G.S. units.

In the next experiment a current of 0·457 ampere was steadily maintained, in such a direction as to oppose the earth's field, in the outermost or No. 4 coil, during demagnetization of the shells as above described, starting as before with a current of 4·7 amperes. The current in No. 4 coil was then broken, and the interior force was found to be positive, that is of the same sign as that of the earth's field, and to have the value 0·00324 C.G.S. units. On restoring

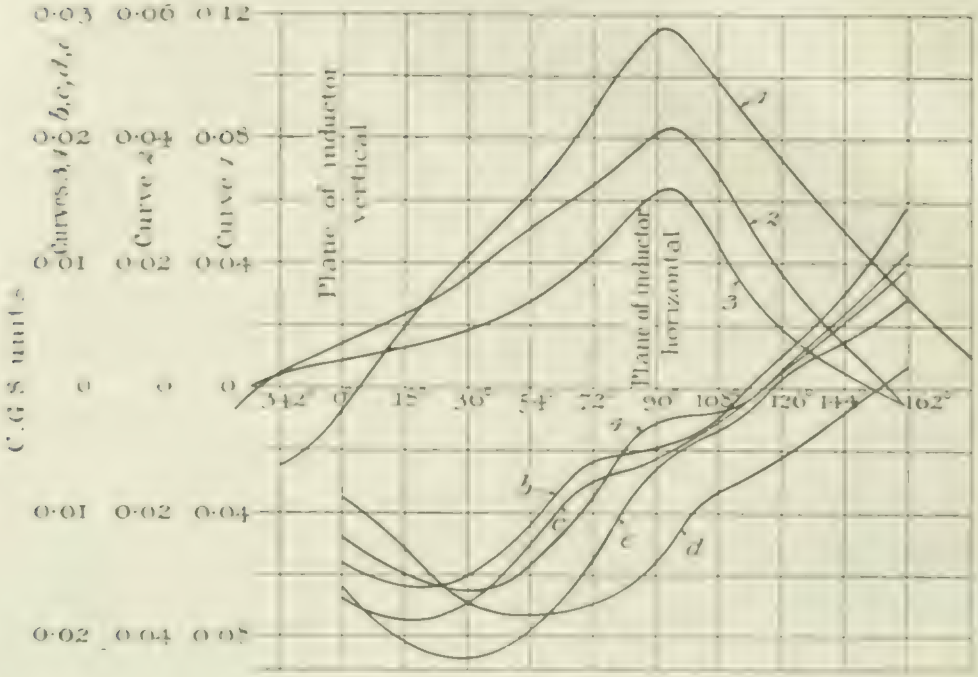
C.G.S units
Curves 3, 4, b, c, d, e
Curve 2
Curve 1
0·03 0·06 0·12
0·02 0·04 0·08
0·01 0·02 0·04
0 0 0
0·01 0·02 0·04
0·02 0·04 0·08
342° 0° 18° 36° 54° 72° 90° 108° 126° 144° 162°
Plane of inductor vertical
Plane of inductor horizontal
1
2
3
4
b
c
e
d

Fig. 3.

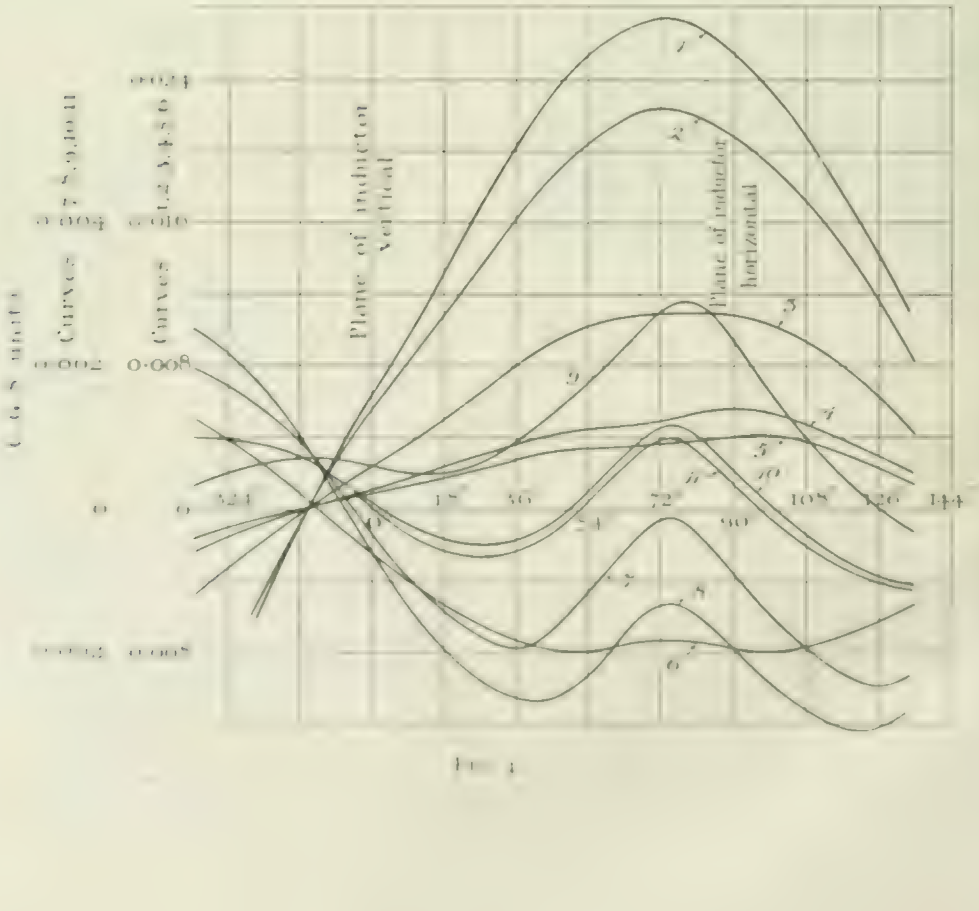
C.G.S units
Curves 7, 8, 9, 10, 11
Curves 1, 2, 3, 4, 5, 6
0·024
0·004 0·016
0·002 0·008
0 0
0·002 0·008
324 0 18 36 54 72 90 108 126 144
Plane of inductor vertical
Plane of inductor horizontal
1
2
3
4
5
6
7
8
9
10
11

Fig. 4.

the current of 0·457 ampere in No. 4 coil, and gradually reducing it by stages during reversal, the force was reduced to 0·00193 and was still positive. The results of this and succeeding experiments are summarized in Table 3.

TABLE 3.

Steady Current in No. 4 Coil, in amperes	Initial Demagnetizing Current in Coils 1, 2, 3, in amperes	Interior force in C.G.S. Units	
		After breaking Current in No. 4 Coil	After Demagnetizing with Current in No. 4 Coil
− 0·457	4·7	+ 0·00324	+ 0·00193
− 0·893	5·0	+ 0·0122	+ 0·0101
− 2·5	9·2	+ 0·0275	+ 0·0224

The figures given in Table 3 show that a positive force of varying magnitude can be produced in the hollow of the shield by demagnetization of the shells when they are surrounded by a magnetizing coil carrying a current which produces a force opposed to that of the earth.

The last recorded experiment in Table 3 is illustrated by curves 1 and 2 in Fig. 4 and the procedure was then to demagnetize the shells, with no steady currents in No. 4 coil, by passing initial currents of ascending magnitude 4·8, 7·5, and 10·2 amperes through coils 1, 2, 3, in series. The force was thus reduced by stages, as shown by curves 3, 4, 5, from its positive value of 0·0224 C.G.S. units, until finally with an initial current of 12·5 amperes a negative force of 0·0073 C.G.S. units, as shown by curve 6, was obtained at about 67° on the axis of abscissæ.

Starting with this negative force, the concluding stages shown in Fig. 4 were reached. A current of 0·675 ampere was maintained in No. 4 coil in such a direction as to oppose the earth's field inside the coil. With an initial current of 1·9 amperes the shells were demagnetized as before, and the current in No. 4 coil was broken. The result is shown in curve 7. The current in No. 4 coil was re-made and reduced by steps during the reversal. Curve 8 was then taken, and shows a negative force at about 70° of value 0·0013 C.G.S. units.

Adopting the same procedure with a steady current of 0·751 ampere in No. 4 coil, and an initial demagnetizing current of 1·9 amperes in coils Nos. 1, 2, 3, curves 9 and 10 were obtained. This final curve has ordinates at angles 315° and 135° of magnitude 0·001 C.G.S. units, and the ordinate at about 70° is 0·00117 C.G.S. units. This force of 0·00117 C.G.S. units is regarded as the true effect of the earth's field in the hollow of the shield. After a rest of three weeks the interior of the shield was again explored by the inductor, and the resulting curve 11 shows that there is a slight change, tending towards the negative force which would be imposed by the earth's field, but for the superposed effects of residual magnetism.

The best results are obtained when the current in No. 4 coil annuls the effect of the earth's field. It is found that currents ranging from about 0·2 to 1 ampere enable good results to be obtained, the best result being with about 0·75 ampere, which was the current previously found necessary to annul the steady effect of the earth.

Assuming the force of the earth to be 0·5, this final result indicates a shielding ratio of 427. Reference to Table 1 shows that for this ratio with four shells the average permeability is higher than 300. It seems possible that the permeability of the innermost shell must be of a high order, with diminishing values for the other shells until the outermost one is reached. The increase in permeability which occurs in iron when it is demagnetized in a magnetic shield would on this theory receive an interpretation.

PRESSURE DROP CURVES FOR COPPER OVERHEAD LINES.

By G. N. Wright, Associate Member.

(Received 18 June, 1912.)

Explanatory Note.—The accompanying curves (Fig. 1) were drawn so that the true pressure drop (i.e. the difference between the voltage at the generating end and the voltage at the receiving end) on a three-phase 40-period overhead line at any load could be found readily and without complicated calculations. By working out numerous examples it has been proved that though these curves were drawn for a 3,000-volt line two miles long with conductors symmetrically arranged and loaded to 1,000 amperes per sq. in., the error for other commercial lengths and loading at that and other voltages is quite negligible [illegible] still greater inaccuracy might be expected in taking a reading from the curve [illegible]

The line drop when the load is other than 1,000 amperes per sq. in. must be found by simple proportion.

The curves will be found to be absolutely correct for a 3,000-volt line two miles long, or an 11,000-volt line 2 × 11,000 ÷ 3,000 = 7 1/3 miles long, or a 20,000-volt line 2 × 20,000 ÷ 3,000 = 13 1/3 miles long, or a 44,000-volt line 2 × 44,000 ÷ 3,000 = 29 1/3 miles long loaded to 1,000 amperes per sq. in.; or for double these lengths loaded only to 500 amperes per sq. in., or for half these lengths loaded to 2,000 amperes per sq. in.

Where the length of line is less or the current density lower, the curve reading will be slightly high, and conversely when the length of line is greater or the current density higher the curve reading will be slightly low; but, as mentioned above, the error is negligible, being less than 1 per cent. for any commercial proposition.

Mr. [illegible] Hay's formula for inductance was used in the

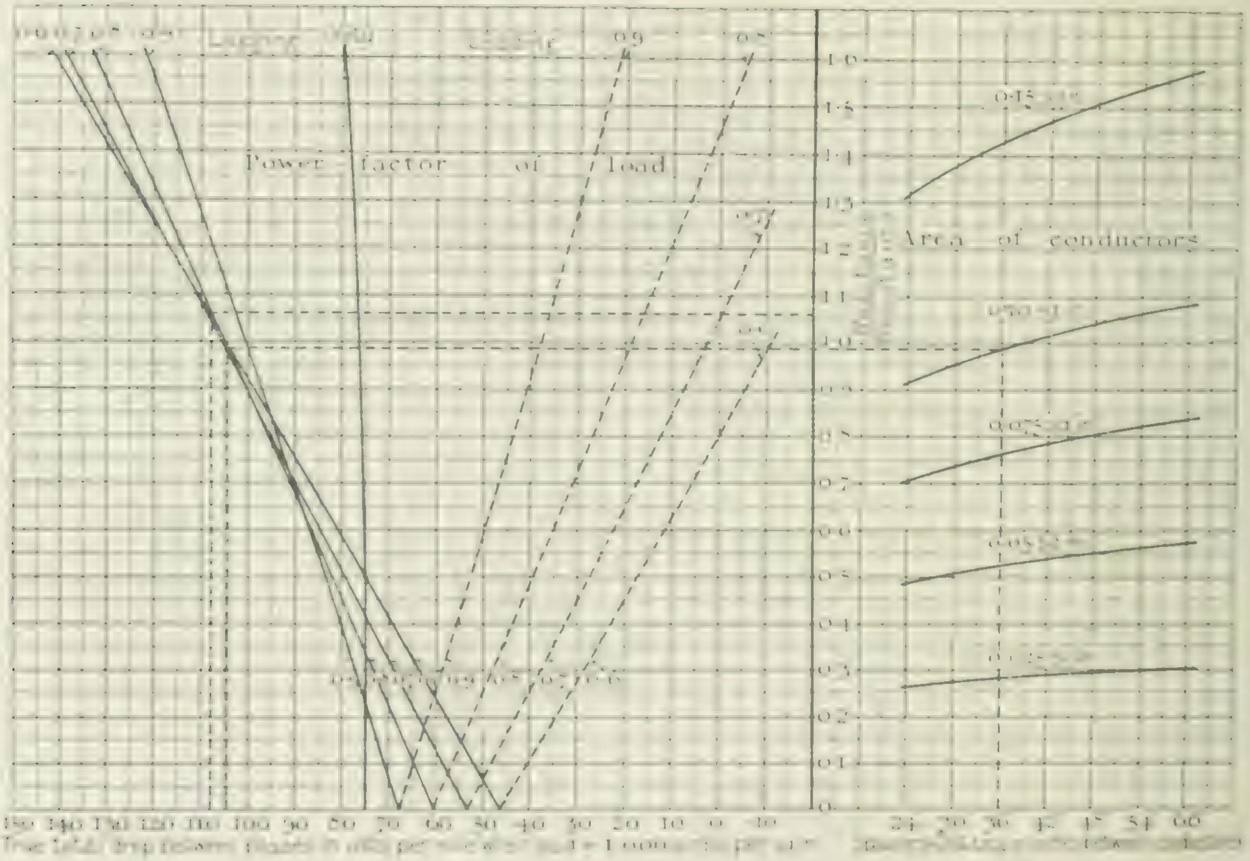

Fig. 1.—Curves showing voltage drop on copper overhead lines.

[illegible]

[illegible]

calculations, namely, inductance per mile of single-phase line in henries $= 14{\cdot}8 \times 10^{-4} \log_{10} (d/r)$.

Capacity has been disregarded as negligible, it being assumed that the curves will not be used for voltages higher than those likely to be adopted in this country.

Besides being useful for calculations of voltage drops, the curves bring clearly to light the fact that though smaller conductors give higher inductance than larger ones for the same spacing, the ratio of reactance to resistance for small conductors is less and therefore the actual drop is less at the same loading per square inch for loads with lagging power factors.

To make the curves of more general use, the following particulars for conductors in the same plane, for single-phase lines, and for split-conductor lines have been added, and also those for other frequencies, though the curve does not allow for skin effect which would be present at very high frequencies :—

If the line under consideration has conductors arranged in the same plane, a point 7 per cent higher should be taken on the reactance/resistance line before looking across to the left.

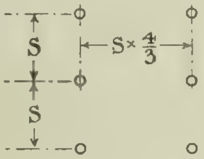

FIG. 2.

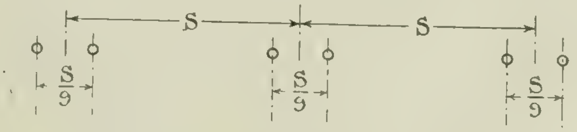

FIG. 3.

If the line is a single-phase one, 15 per cent should be added to the drop obtained from the curves.

If the periodicity is other than 40 a new point should be taken on the reactance/resistance line corresponding to the original reading multiplied by (new periodicity/40) before looking across to the left.

If the line under consideration has aluminium conductors a new point should be taken on the reactance/resistance line corresponding to the original reading multiplied by 0·6 before looking across to the left, and the drop obtained should be multiplied by 1·66.

It may be seen from the curves that in comparing a copper line with an aluminium line, the latter having conductors of equal conductivity to the conductors on the former, the true drop for the same load at the same power factor* is less for the aluminium line than for the copper line if the spacing is the same in both cases, but if the spacing of the aluminium conductors has to be increased on account of the greater sag, this almost exactly neutralizes the saving.

If the line under consideration is a split-conductor one with conductors arranged as shown in Fig. 2, consider one circuit only (the drop on the other circuit will naturally be the same), and after finding the point on the reactance/resistance line corresponding to the size of conductor and spacing, add 7 per cent on account of conductors being in the same plane, and to this new figure add 6 per cent (this covers the effect of mutual inductance between circuits) before looking across to the left.

If the line under consideration is a split-conductor one with conductors arranged as shown in Fig. 3, consider one circuit only as before, and after finding the point on the reactance/resistance line corresponding to the size of conductor and spacing, add 7 per cent on account of conductors being in the same plane, and to this new figure add 40 per cent (this covers the effect of mutual inductance between circuits) before looking across to the left.

The percentages are average figures, as they vary slightly with different spacings and sizes of conductors, but when used for any commercial proposition the error, if any, is very slight and may be considered negligible.

It may be seen from the above that the pressure drop on a split-conductor line is considerably less than that on a single-circuit line having conductors of double the area and carrying the same load if this load is at a lagging power factor.

To ascertain the short-circuit current of any three-phase line (i.e. the current which would momentarily flow if the three phases were dead short-circuited at the receiving end and the voltage at the generating end was kept constant), let

a = value of reactance/resistance for this line as obtained from the curve.
b = length of the line in miles.
c = area of each conductor in square inches.
d = voltage at generating end.

Then, short-circuit current in amperes

$$= \frac{d \times c \times 40}{b \times \sqrt{(1 + a^2)} \times 3}.$$

If the short-circuit current of a single-phase line is required, or if only two of the three phases are short-circuited, the above formula may be used, but 13 per cent must be deducted from the result obtained.

Incidentally the points where the lines giving the power factor of the load intersect the line for which

$$\frac{\text{reactance}}{\text{resistance}} = 0$$

give approximately the true pressure drop between phases per mile on a three-core cable when the conductors are loaded to 1,000 amperes per sq. in., and the approximate true drops for other lengths and loading may be found by simple proportion. No allowance for capacity is made, but the capacity current in most cables makes very little difference to the actual drop. The results given by the curve are of course the more correct the lower the voltage at which the cable is working and the heavier the amperes per sq. in. per conductor.

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* When this power factor is a lagging one.

STANDARD CLAUSES FOR STREET LIGHTING SPECIFICATIONS.

NOTE.

In December 1911, a Committee was appointed by the Institution to prepare a Standard Specification for Street Lighting. The Committee was subsequently enlarged by the addition of representatives of The Institution of Gas Engineers, The Institution of Municipal and County Engineers, and The Illuminating Engineering Society, and was constituted as follows :—

STREET LIGHTING SPECIFICATION (JOINT) COMMITTEE.

W. H. Patchell (*Chairman*).
The President I.E.E. (*ex-officio*).

F. Bailey.
J. W. Bradley.
K. Edgecumbe.
H. T. Harrison.
Professor J. T. MacGregor-Morris.
S. L. Pearce
A. P. Trotter.

AND

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
Representing The Institution of Municipal and County Engineers.

J. Bond.
[illegible]
S. Y. Shoubridge.
[illegible] Watson.
Representing The Institution of Gas Engineers.

L. Gaster.
F. W. Goodenough.
J. W. [illegible]
Representing The Illuminating Engineering Society.

After certain preliminary clauses had been agreed upon, selected London streets were classified by municipal surveyors serving on the Committee and photometric measurements were taken in each of them.

The results obtained were embodied in further clauses which appeared to be generally acceptable to all the members of the Committee, subject to the settlement of a fundamental difference of opinion between the majority and the remaining members of the Committee as to the [illegible] on which the Specification should be based.

The opinion of the majority was that the proper basis is [illegible] "minimum horizontal illumination," and this was incorporated in an interim draft for the consideration of the Councils concerned. Counter-proposals that "candle-power" should be the basis were received from the Institution of Gas Engineers, but the Specification was substantially accepted by the Councils of the Institution of Municipal and County Engineers and of the Illuminating Engineering Society, and also by the electrical representatives on the Committee.

With the object of thoroughly ventilating the question in the hope that some means might be found of reconciling the views of the majority with those of the minority, the Specification was discussed at a general meeting of the Illuminating Engineering Society on the 15th April, 1913, in the form of a paper by Mr. A. P. Trotter containing the draft. The views there expressed were considered at subsequent meetings of the Committee, when it became evident that the two bases proposed were irreconcilable and that unanimous adhesion to either basis would be unobtainable.

Further efforts have been made to frame such a clause as would be acceptable to the minority but without result, and as the matter has now been under consideration for over six years it has been decided to publish the Specification as it now stands as a Majority Report (see page 523). It is hoped that it may be found useful when the methods of street lighting are reviewed after the War.

STATEMENT BY MINORITY OF THE COMMITTEE.

The Council of the Institution of Gas Engineers at an early date expressed their opinion that the appraisement of street lighting in terms of the minimum horizontal illumination obtained is not a correct method of measuring the illumination given by street lamps, inasmuch as it is affected by the light given from other sources, of varying intensity in different places and at different times. At a meeting of the Joint Committee held on the 24th January, 1916, it was agreed to appoint a Sub-Committee to consider and report on a proposal to amend the Specification so as to ensure a statement of both maximum and minimum horizontal illumination with defined ratios. Such an amendment would have considerably [illegible] removed the objection to the Specification as previously drafted. It is regrettable that the Sub-Committee were unable to find a suitable form of words to bring forward, and that no such amendment is therefore to be included. The Council of the Institution of Gas Engineers formally express their opinion that contracts for street lighting should be based on the average candle-power of light sources ascertained at two or three defined angles. This, in the opinion of the Council of the Institution of Gas Engineers, is the simplest and most correct method, and, moreover, would avoid the possibility of disputes arising from the more or less uncertain measurement of minimum horizontal foot-candle values.

STANDARD CLAUSES FOR INCLUSION IN A SPECIFICATION FOR STREET LIGHTING.

1. *Intent of tender.*—The Form of Tender headed "Lighting of . . . ." includes the provision, fixing, connection, and maintenance of all lamps necessary for obtaining the illumination specified in the Schedule and according to the provisions of the Specification.

2. *Unit of measurement.*—This Specification is based on illumination, the unit of measurement being one foot-candle.

3. *Classification of streets.*—For convenient reference the streets are classified as having a minimum illumination as follows :—

Class A	0·01 foot-candle
,, B	0·025 ,,
,, C	0·04 ,,
,, D	0·06 ,,
,, E	0·10 ,,

Street lighting at a lower minimum illumination than 0·01 foot-candle may be specified by the height and distance apart of the lighting units and the candle-power as measured in the direction of the thoroughfare at an angle of 10 degrees below the horizontal.

4. *Minimum illumination.*—The "minimum illumination" of a street means the minimum illumination on a horizontal plane at a height of 3 ft. 3 in. above the ground-level and may be measured by means of :—

(*a*) Any suitable illumination photometer, or
(*b*) Any suitable photometer adapted for use in the street which will measure the candle-power of the lamps in those directions which meet at the point of minimum illuminations. In this case the minimum illumination will be calculated by adding together the values of the illumination received from each lamp that materially contributes to the result. In this connection a useful table will be found in Appendix A.

5. *Special illumination.*—The special illumination of certain positions indicated on the accompanying map (marked . . .) such as the corners of cross streets are dealt with by specifying the positions and heights of lamps and illumination at those points.

6. *Type of photometer.*—The photometer shall be of the (insert name) type or of such other type as may be agreed between the parties.

7. *Position of lighting units.*—The approximate positions of certain lighting units are indicated on the accompanying map and are correct within the limits of deviation marked thereon. The Contractor shall indicate the positions of all the lighting units either by completing the said map or by a descriptive Schedule accompanying his Tender.

8. *Particulars of lighting units.*—The number and detailed particulars of each type of lighting unit included in the Tender must be included in the space provided for that purpose in the Schedule, including the height at which it is proposed to place the centre of light of each type of unit above the street surface, subject to the minimum given in the Schedule.

9. *Drawings.*—Drawings of all details as required by the Specification shall accompany the Tender.

10. *Samples.*—Samples shall be submitted if required before the acceptance of the Tender.

11. *Number of lighting units.*—The Tender shall include a quotation for the provision, fixing, and connection of the necessary apparatus, and the price per annum for maintenance and for . . . hours' lighting, in respect of each type of lighting unit as called for by the Form of Tender.

12. *Additional lighting units.*—The Contract will provide for additional lighting units if required, such increase not to exceed . . . per cent, and to be paid for at the quoted rate per lighting unit.

13. *Tests.*—A test of the illumination shall be made under such normal atmospheric conditions as will not appreciably affect the accuracy of the result and at a fairly selected point not being in the shadow of a mantle, lamp, electrode, lantern bar, post, tree, or other obstruction.

When a minimum illumination or candle-power of lighting unit is specified it shall be held that such minimum is obtained if the average of the measurements of any three minima between consecutive lighting units of the same type does not fall below it.

14. *Contract to be signed.*—The Tender shall contain the usual clause that the provisions, conditions, and prices named therein shall form the basis of a Contract containing the necessary legal provision to ensure its fulfilment.

NOTE 1. *Special clauses.*—Each Specification may contain clauses in addition to the foregoing.

NOTE 2. *Detail prices.*—In cases where the Specification only calls for the supply, delivery, erection, and connecting up of the lamps, or any of these items, the following further details may be called for :—

(*a*) The cost of the necessary fittings (excluding cost of renewable parts such as lamps or mantles) delivered on site.
(*b*) The cost of erecting the same.
(*c*) The cost of connecting the same to source of supply.
(*d*) The quantity of gas, oil, or electricity required to maintain the degree of illumination specified and the pressure at which such gas, oil, or electricity is to be supplied.

NOTE 3. *Detail maintenance.*—It may also be necessary in some cases to call for the cost of maintenance divided up under the following headings :—

(1) Maintenance of all parts such as posts, fixtures, or fittings, including cost of cleaning and painting at stated intervals.
(2) Maintenance of all renewable parts such as mantles, lamps, or carbons, including labour connected therewith.

In addition to the necessary legal provision to ensure its [illegible]

(1) [illegible] prices to be quoted.

(2) [illegible] as may be necessary for the convenience and safety of the [illegible]

(3) Indemnifying the Council against claims arising out of the execution or maintenance of the work or [illegible]

(4) [illegible]

(5) Defining the responsibilities of the Contractor and to [illegible] Tender with due regard to practical difficulties, the following clause being suggested as a guide :—

The intention of the Contract is that during the maintenance guarantee period of a Construction Contract and during the term of a Lighting Contract the Contractor shall assure himself that the lamps he provides are during lighting hours fulfilling in all respects the requirements of the Contract and he shall not claim relief from the conditions of the Contract on the grounds of non-notification on the part of the Council of any failure to comply with the terms of the Contract.

[illegible] A.

The table below, which was originally calculated by Mr. Haydn T. Harrison to show the candle-power required to produce a minimum illumination of 0·01 foot-candle on a horizontal plane 3 ft. from the ground, midway between two lamps of a given height and distance apart, has been recalculated by Mr. M. Wilson of the Board of Trade for a height of 3·28 ft. instead of 3 ft. 3 in. referred to in Clause 4, thus approximating more closely to the metre. The difference in the result, less than half of one per cent, is of course inappreciable. The following is an example :—

H = height of lamp, h = height of photometer, D = distance apart of the lamps, all in feet. Let H = 12, h = 3·28, D = 100. Then $(H - h)^2 + (D/2)^2 = 257604$. Since D/2 is 50, look out in a table of squares and cubes the square of a number rather larger than 5,000, the nearest square to 25,760,400, and take its cube. This number is 5,075, the square is 25,755,625, and the cube is 130,709,796,875, of which the first five figures are sufficient. But the fourth figure of the square is not an exact fit, and by proportion the cube is taken as 130,740. As two lamps contribute to produce 0·01 foot-candle, the cube is divided by $2(H - h) \times 100$. Then 130,740/1,744 = 74·07, which is given in the table as 75. If the photometer is 3·25 ft. [illegible]

[illegible] horizontal plane [illegible] D is the distance apart of the lamps. θ is the angle which the ray makes with the horizontal.

	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		30 ft.		[illegible]		
D	θ	I	θ	I	θ	I	θ	I	θ	I	θ	I	θ	I	θ	I	D
[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]	9·4	[illegible]	[illegible]	34	[illegible]	[illegible]	[illegible]	[illegible]	9·2	[illegible]	[illegible]	50
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	10·3	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	17·8	15	[illegible]	[illegible]	[illegible]	[illegible]	11·0	[illegible]	10·4	37	[illegible]	44	[illegible]	49	12·2	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	13·4	[illegible]
[illegible]	[illegible]	[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	13·4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14·3	45	[illegible]	[illegible]
[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]	22·9	[illegible]	[illegible]	[illegible]	[illegible]	31	[illegible]	37	[illegible]	43	[illegible]	70
[illegible]	[illegible]	[illegible]	13	[illegible]	17	27·7	[illegible]	23·2	24	20·7	[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	75
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33·1	[illegible]	[illegible]	[illegible]	24·4	27	[illegible]	34	20·8	[illegible]	21·1	80
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39·3	[illegible]	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	85
[illegible]	[illegible]	[illegible]	11	[illegible]	14	46·2	[illegible]	38·0	[illegible]	[illegible]	[illegible]	[illegible]	31	26·8	[illegible]	26·3	90
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34	29·3	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22	[illegible]	[illegible]	[illegible]	33	32·6	[illegible]
[illegible]	[illegible]	126·6	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26	42·8	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]	85·0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53·0	20	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	12	[illegible]	14	90·4	[illegible]	[illegible]	22	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5	[illegible]	[illegible]	[illegible]	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	93·9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	317·7	[illegible]	[illegible]	[illegible]	202·8	[illegible]	161·5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5	385·0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22	98·7	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	347	[illegible]	[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]	155	20	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible]	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1045	4	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	553	[illegible]

PROCEEDINGS OF THE INSTITUTION.

45TH ANNUAL GENERAL MEETING, 17 MAY, 1917.

(Held in the rooms of The Institution of Civil Engineers.)

Mr. C. P. SPARKS, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 26 April, 1917, were taken as read, and were confirmed and signed.

The President announced the result of the ballot for the election of new Members of Council (see page 411), and a vote of thanks was passed to the scrutineers of the ballot (Mr. J. O. Girdlestone, Mr. F. B. O. Hawes, and Professor J. T. MacGregor-Morris).

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Messrs. A. Dover and H. L. Leach were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Associate Members.

Black, Robert Thomas C.
Blackiston, Hampton Ernest.
Butterfield, James Henry.
Catterson, Selsby Mitchell.
Ellis, Augustine ap.
Martin, Thomas Dawson.
Munday, George William.
Murray, John Glassford.
Pearson, George William.
Penny, George Ernest R.
Robertson, Robert Knight.
Rutter, Gordon Hagreen.
Smith, Arthur William B.
Thomas, William John.
Webb, Herbert James G.

Associates.

Nickless, John Ernest.
Polloy, James Hillsdon.
Zapp, Albert.

Graduates.

Gibbins, John.
Harriss, George Sydney.
Leaver, Henry.
Lee, Zoau Nion Henry.
Pike, Frederick Andrew.
Redgrave, Harry Conway.
Ross, George.
Stubbs, Albert.
Taylor, Albert Jesse.
Wakeling, Arthur Beverly.
Xenakis, James J.

Students.

Baird, William.
Barry, William Cyril.
Butler, Archibald Stephen.
Cho, Wong Tai.
Hazelwood, Harry.
Howard, Henry John.
Kwong, Au Kim.
Lai, Hau Chin.
Lewis, Edward Weston.
Mahon, Brian Ernest.
Ogilvie, Harold Erskine.
Peek, Arthur Stanley.
Strickland, Albert.
Ward, Percy.
Watts, Arthur James C.

TRANSFERS.

Associate Member to Member.

Chorlton, Alan Ernest Leofric.
Cross, William.
Douglas, Clifford Hugh.
Hill, Edmund Lewin.
Joyce, Sydney Arthur.
Twiss, George Victor.

Associate to Member.

Macrory, Robert Valentine.

Graduate to Associate Member.

Bamford, Henry Martindale.
James, Ernest Frederick.
McIntyre, Douglas Wilson.
Slorach, James William.

Student to Associate Member.

Gill, Percy Leach.
Newbury, Alfred Donald.

Student to Graduate.

Penard Fernandez, Enrique.
Tyrrell, Frederick.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Building Fund : M. L. Delanoy.

Library : H. Allcock, The Association of Supervising Electricians, Messrs. Crosby Lockwood and Son, A. Dickinson, R. B. Matthews, and The Smithsonian Institution.

Mr. Sparks.

The PRESIDENT : Before taking the ordinary business for which we have been called together, there is a matter of special importance with which I propose to deal. After $2\frac{1}{2}$ years of war on an unprecedented scale, in which we and our kith and kin have staked our all in the interests of civilization to protect smaller nations against Prussian militarism, and after unspeakable outrages on the mercantile marine of the world, including the sinking of the *Lusitania* without warning, and the torpedoing of hospital ships carrying both friend and foe, it is with the greatest satisfaction we see that the remaining Anglo-Saxon nation has definitely enrolled itself on the side of the Allies, thus endorsing the correctness of our country's decision in August 1914. The Council considered this matter on the 26th April, and decided to send a message of greeting to our kindred Institution in America, but in view of the annual general meeting it was decided to postpone action until to-day. I have now to propose that the following message be sent by cable :—

" The President, Council, and members of the Institution of Electrical Engineers send hearty greetings to their brethren of the American Institute of Electrical Engineers, and hereby express to them their sincere appreciation of the entry of the great American nation into the War on behalf of civilization and its ideals, and of the deep significance of their action for the cause of the British [illegible] and its Allies.

[illegible] engrossed on vellum and, after being sealed and signed by the President, the President-elect, and the Secretary, will be despatched to [illegible]

Mr. C. H. Wordingham: It affords me the keenest pleasure to second this proposal. There are few, if any, of us who do not number among our friends many individual Americans, and I am quite sure that our experience of them as individuals has led to our entertaining for them the highest possible regard. We look upon them as [illegible] the word. Many of us—unfortunately I am not among the number—know America as well as individual Americans. They have travelled in America, and they have experienced the hospitality of Americans, which is so well known all over the world, and they have found how ready they are to impart their knowledge to their brother engineers. And those who have come back have, one and all, been doubly impressed with the American nation as a whole, so that, both as individuals and as a nation, we regard them with the greatest cordiality. I think it is safe to say that many individual Americans for a long time have wished that their nation were taking part in this War which has been going on for so long, and it must, therefore, be to them a great source of gratification that their nation as a whole has now taken action on the lines that they as individuals would have wished, and have been wishing, for a long time past. That gratification is greater still for ourselves because we like to [illegible] have, as the President has already said, their endorsement of our action in taking part in this stupendous War. One cannot help feeling that if these two great nations, the American nation and the British nation, can purge themselves of the foul cancer of the Germans that has invaded them, there may, in the not very far distant future, come [illegible] great federation of the whole Anglo-Saxon race. [illegible] make for that far greater ideal, the re-union of Christendom. I have the very greatest pleasure, therefore, in seconding [illegible]

The proposal was then put and unanimously adopted.

The President then gave a summary of the Annual [illegible] of the Council for the year 1916–17 (see page 311).

The President: I should like to add in connection with the inquiry into the nationality of members, that the [illegible]

As a result, 41 members were struck off under the new Article of Association, and there is no reason to suppose that there are now in the Institution any members to whom the Article would apply; but if any of our members know of any such perhaps they will send particulars to the Secretary, and the Council will then make further investigation. If any member will write to the Council, or to me, or to Mr. Wordingham as my successor, his name will not be disclosed. I now move "That the Annual Report of the Council as circulated be received and adopted." Mr Sparks.

Mr. C. H. Wordingham seconded the resolution, and there being no discussion, the motion was then put and unanimously adopted. Mr Wordingham.

Mr. J. E. Kingsbury: I have very much pleasure in moving "That the Statement of Accounts and the Balance Sheet for 1916, as presented, be received and adopted," and perhaps I may be expected to make some comments on the Accounts. I do not propose to make those comments at any length, because it will be noticed that the statement of income and expenditure has in the margin the comparative figures for last year, a method which has been adopted on the suggestion of a member at the last Annual Meeting. The result of the year from the income point of view is, as stated in the Report, a surplus of income over expenditure of £3,776 17s. 7d., which is £1,929 16s. 7d. greater than that of the previous year. That £1,929 is made up in part by increased income, amounting to £664 7s. 8d., and in part by a net decrease of expenditure of £1,265 8s. 11d., which I think it may be claimed is the result of the efforts of the Council to conform to the spirit of the age in the exercise of economy so far as it can be done with due compliance with the objects and aims of the Institution. I may say, in regard to the items of expenditure in which increases have been incurred, that the only increases of importance are in the items of National Service and Research, the latter of which may also be regarded as an important form of National Service. The total amount of our assets shown in the Accounts is £120,798. We should get a better idea of the figures that we really have to deal with on behalf of the Institution if we eliminated from those figures a sum of £6,318 18s. 5d., which represents sums that do not belong to the Institution at all, but are simply trust funds in the Institution's hands. That amount appears on both sides of the balance sheet, and consequently if we reduce the figures by that amount, we have £114,479 as assets and £36,290 as liabilities. Quite a ready method of finding what those liabilities consist of is to deduct £32,719 owing on mortgages, which leaves as the other liabilities, £3,571. If a comparison is made of our standing to-day with what it was last year, it will be found that we are £4,453 better off. The net assets amount to £78,188 14s. [illegible] These assets consist of properties, securities, cash, and some amounts due to us. The properties of the Institution, taking the Institution building at £70,901, deducting the mortgage and adding the sinking fund, will give £51,809 in the Institution building. Then there is the property in Tothill-street, which cost £10,000 odd; if we deduct its mortgage we have £[illegible] in land and bricks and mortar in Tothill-street, and we also have the knowledge that this property is in a very improving neighbourhood. Then there are investments of £10,478, on the same basis of Mr Kingsbury.

Mr. Kingsbury.

valuation as the preceding accounts. It was suggested at the last Annual Meeting that it might be desirable to take those securities at their value on the date of making up the accounts instead of at cost. That has been very carefully considered, and the result is that the accounts in the present form continue at cost. Then there is in cash and what is as good as cash, £6,414. Adding the library, furniture, and a somewhat useful stock of paper, sundry debtors, and items paid in advance, makes a total of £81,760, from which have to be deducted those liabilities other than the mortgage, to which I referred just now, of £3,571 13s. 9d., which gives the net assets as £78,188. I do not think there is anything else for me to do except to move the Resolution, and to say that if any member desires any information I shall be glad to give it to him if it is within my knowledge.

The resolution was seconded by the President, and after a question by Mr. L. B. Atkinson in regard to life compositions, which was answered by Mr. Kingsbury, the President, and Mr. S. Sharp, the resolution was put to the meeting and carried unanimously.

Mr. Kingsbur

Mr. Spar

The PRESIDENT: I now have to propose "That the best thanks of the Institution be according to the following officials for their valuable services during the past year:—The Honorary Secretaries of the Local Sections; the Local Honorary Secretaries and Treasurers abroad; the Honorary Treasurer, Mr. J. E. Kingsbury; the Honorary Auditor, Mr. Sidney Sharp; and the Honorary Solicitors, Messrs. Bristows, Cooke, and Carpmael."

Mr. Chattock

The resolution was seconded by Mr. R. A. CHATTOCK and was carried unanimously.

Mr. Swinton.

Mr. A. A. C. SWINTON: I have much pleasure in proposing "That Mr. Sidney Sharp be elected Honorary Auditor, and Messrs. Allen, Attfield & Co. Auditors for the year 1917–18."

Mr. Atkinson

This motion was seconded by Mr. L. B. ATKINSON, and was carried unanimously.

The meeting adjourned at 6.55 p.m.

SPECIAL GENERAL MEETING OF CORPORATE MEMBERS, 17 MAY, 1917.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. P. SPARKS, President, took the chair at 7 p.m.

The notice convening the meeting was taken as read.

Mr. Sparks.

The PRESIDENT: I will briefly explain the object of the meeting. Last year we were faced with a difficult problem when dealing with enemy members. We had to send out a definite resolution which had to be considered and voted upon by the members present at the meeting; that is to say, the whole of the members who were not within easy reach of London were in a sense disfranchised. Our attention was drawn to that matter, and it was then suggested by the Committee of the Manchester Local Section that, to prevent future difficulties, the Articles of Association should be amended so as to allow every member as far as possible to record his vote, even if he could not be present at the meeting. A small committee was set up by the Council, and, following the advice of the solicitors, based on counsel's opinion, the committee brought up a short report advising that if an amendment were made to the Articles it should allow proxy voting in the common form used by all public companies. It seems to me desirable that we should adopt the common form and not have something special for the Institution. I feel that while there are some disadvantages—slight in my opinion—in having this form of proxy voting, those disadvantages can easily be overcome by the fact that if there is any great controversial question, informal meetings may be held in different parts of the country and, if necessary, a report of those informal meetings could be circulated to every member, so that they could take action in the best interests of the Institution. The question may be asked: Why are we only making this one amendment to the Articles? The answer is that during the War I do not consider it right for the time of members to be taken up in considering general alterations, but we should amend a fundamental principle such as this one. Having amended the constitution by this one alteration, the Articles can then be amended where necessary in future years. I now move the following resolution:—

Mr. Spar

That the Articles of Association of the Institution be altered by adding thereto the following new Articles to be numbered 80*a*, 80*b*, 80*c*, 80*d*, 80*e*, 80*f*, 80*g*, and 80*h* respectively, that is to say:—

80*a*. Votes may be given at all Annual or Special General Meetings either personally or by proxy. On a show of hands every member of any class present in person and entitled to vote at such meeting shall have one vote. In case of a poll every member of any class present in person or by proxy and entitled to vote at such meeting shall have one vote.

80*b*. No person shall be appointed a proxy who is not entitled to vote at the meeting for which the proxy is given.

80*c*. The instrument appointing a proxy shall be in writing under the hand of the Appointer or his Attorney, and whether given for a specified meeting or otherwise shall as nearly as circumstances will admit be in the form or to the effect following:—

THE INSTITUTION OF ELECTRICAL ENGINEERS.

I of
being (a Corporate Member *or* an Associate as the case may be) of the above Institution hereby appoint
of
or failing him of
as my proxy at the (Annual General Meeting, Special General Meeting of Corporate Members and Associates *or* Special General Meeting of Corporate Members as the case may be) of the Institution to be held on the day of 19 and at any poll held in connection therewith.

As witness my hand this day of 191 .

Signature..

Class of membership in I.E.E. ....

80*d*. The instrument appointing a proxy and the power of attorney (if any) under which it is signed shall be deposited at the registered office of the Institution not less than forty-eight hours before the time for holding the [illegible] ig was originally held within six calendar months [illegible]

80e. A vote given in accordance with the terms of an [illegible] is death of the principal or revocation [illegible] s previous intimation in writing of the [illegible] or revocation shall have been received at the registered office of the Institution.

80f. A poll may be demanded by the Chairman of any [illegible] Special General Meeting or by any three persons [illegible] taken in such manner and at such time [illegible] t days next after the meeting and at [illegible] mediately or after an interval or on adjournment and the result of the poll shall be deemed to be the resolution of the meeting at which the poll was demanded. The fact that a poll has been demanded shall not prevent the [illegible] ce of the meeting for the transaction of any [illegible] ther than the question on which the poll has [illegible] l. A demand of a poll may be withdrawn. [illegible] l be given of a poll not taken immediately.

80g. In the case of an equality of votes the Chairman of the meeting shall both on a show of hands and at a poll have a casting vote in addition to his personal vote.

80h. The quorum at any Annual or Special General Meeting shall be five of those persons entitled to be present and vote thereat and no business shall be transacted at any [illegible] ng unless the quorum be present at the commencement of the business. If a quorum be not present within a quarter of an hour from the time appointed for holding the meeting the meeting shall be dissolved.

Mr. C. H. **Wordingham**: This question of proxy voting [illegible] because it seems to me essential for the well-being of the Institution that the whole of the membership should take [illegible] interest in its work and should have the power of [illegible] welfare. This matter has been most carefully considered [illegible] ncil, and I am convinced that the move is one that is likely to be of the utmost benefit to the Institution. We have only to consider the attendance to-night, when there are possibly about 30 members present—and a large proportion of these members are on the Council—out of our total of nearly 7,000, to see how absurd it is that such a small meeting as this should be [illegible] ntal changes in the Articles of [illegible] t that evil and to ensure that every Corporate Member shall have the opportunity [illegible]

[illegible] like this differ fundamentally from commercial [illegible] y. In an institution like [illegible] te and only one vote; [illegible] capital of the Company may be in the hands of one man, and if he could not attend a meeting it would be obviously unfair that he should not be represented. I have had some experience of company business and proxy voting and I hope that the Council fully understand the snare which they are laying for themselves. Supposing the Council determine that some particular alteration in the Articles should be made, and they send out a notice to that effect, are they going to ask for proxies for themselves upon that particular point? If they do not, they may be beaten. In companies it is the usual thing for the directors, in sending out a notice of a meeting, to send out proxy forms asking for proxies for themselves, because otherwise a few people, a clique, may get together with their friends and their friends' friends, and may easily collect a sufficient number of proxies to swamp a meeting such as this. If this resolution is carried, it will be necessary for the Council, every time they send out a notice of a meeting, to ask for proxies for themselves, and I do not think that is a very dignified position for any Council to have to take up. The list of societies sent out with the notice of this meeting is very incomplete. I believe that no proxy voting is allowed by the Royal Society, the Royal Institution, the Royal Society of Arts, the Chemical Society, the Physical Society, the Royal Academy, or other bodies whose acts are governed by voting. Take also the House of Lords and the House of Commons. Again, a Member of Parliament cannot be elected by proxy. I think it is a most dangerous suggestion. I would much rather see power given to anybody at any meeting to call for a poll and that then a postal vote should be taken on the question, and that such postal vote should be binding. In saying all this, however, I am anxious to make it quite clear that I have no desire at all to curb the influence of the country member. On the contrary, I have every wish to give him facilities for recording his vote, and it is only the particular method of voting by proxy that I think objectionable.

The **President**: Before asking other members to speak, I will try and answer Mr. Swinton's remarks. The committee have had quite a number of meetings and have discussed all kinds of alternatives, and at one time they were strongly in favour of the postal vote, but they were informed that under the Companies Acts a postal vote can only indicate an opinion and has no legal effect. Finally the Council unanimously adopted the report of the committee, giving effect to the recommendations now put forward. At the same time we recognize the difficulty with regard to the sending out of proxies, and it is to be left to future Presidents and Councils to decide the question on each occasion. We have a unanimous Council and unanimous Local Sections, so that if we are making a mistake we are making a mistake with our eyes open.

Mr. J. S. **Highfield**: I am inclined to support what [illegible] mentioned at the beginning is of great importance. He pointed out that in order to make the proxy effective it will be necessary to canvass the country and hold meetings [illegible] question I have no doubt that perhaps 10 meetings might [illegible] 1,000 members altogether, which is still only one-seventh of the total membership.

[illegible] We [illegible] a report of those

Mr. Sparks.

meetings, so that every one of the 7,000 members would know what was said.

Mr. Highfield.

Mr. HIGHFIELD: Not more than 1,000 out of the 7,000 members would read the report, and therefore the proxy voting would never be very intelligent voting. The principle on which this Institution has been ruled hitherto is that the members elect their Council and their Local Section Committees. That is all done by the whole body of members, and the constitution is such that very frequent changes in the membership of the Council take place. What I feel is that, once the Council are elected, the proper way to get them to do the best possible work is to put the whole responsibility upon them. We may get an exceptional case like that of last year; but even then the postcard method gave the Council a guide in a very difficult question and proved a perfectly adequate method of obtaining the views of individual members. I feel that voting by proxy is first of all rather undignified, because I am certain that if the Council have to deal with a controversial matter they will have to send out proxy forms in order to get their proposals passed. It will also be awkward for Members of Council to attend all these local meetings. For those reasons and for one more I support Mr. Swinton in his view that proxy voting is undesirable. The other reason is this. I look upon this as a very great change in the method of conducting the business of the Institution. It is taking away from the Council a responsibility which they now have. That great change it is proposed to carry by a vote of the small number of members here present, so that we have not got away from the difficulty. It seems to me that the least that should be done is to take a postcard vote on this question, in my view at least as important as the former difficulty of dealing with enemy members.

Mr. Rosling.

Mr. P. ROSLING: As one who has been for many years a country member I should like to give my vote in favour of the Council's suggestion. I do not think it is quite fair to compare this with a business meeting. Here it is a case of one man one vote. If a clique can be formed of 400 or 500 members, it is an expression of opinion that should have some weight, and that is a point which should be considered. If only 40 or 50 members in London want something done, and by proxy voting they can be stopped by 400 or 500 provincial members, they ought to be stopped. I think that is a strong argument for proxy voting. I do not see why it should be necessary for the Council to send out proxy papers. The resolution provides that a member who is unable to be present in person to vote has the right by filling up a proxy paper to employ a proxy and would apply for a form. In the past, country members have felt that the London members ran the Institution in their own way, and there has been a little irritation; but directly they are allowed to vote by proxy that irritation will be removed, and they usually will not vote.

Mr. Atkinson.

Mr. L. B. ATKINSON: I do not think the point that Mr. Swinton has raised is a real difficulty. In the case of a business meeting when some question arises and it is known that there will be a difference of opinion everybody marshals all his forces right away, and proxies are issued. Suppose such a question as that under consideration to-day should arise and that we were going to vote by proxy; it would not be necessary for the Council to send out proxies. They would hold the meeting and take the proxies that were sent in. The Council may fix a date for the discussion of any resolution so far ahead that everybody can then give his view by proxy on the matter. In other words, it is not necessary for the Council to ask for proxies before the meeting. This Institution has made a great feature of its Local Sections, which are a great source of strength to the Institution and give many members an interest that they would not have in merely a London Institution. When we were dealing a short time ago with the difficult question of enemy members I was exceedingly nervous right up to the last minute, even when we knew what the result of the postal vote was, because I was convinced that any resolution could be swamped at the last moment by a resolute and well-organized minority. Therefore I am in favour of giving all members the right of expressing their views. It rests with the Council to see that they do not allow snatch votes by proxies. I do not think it is necessary for the Council on every occasion to take the step of sending out proxies, which Mr. Swinton thinks is undignified. When the time comes that the Council think the wishes of the Institution or their own proposals may be overruled, they can ask for proxies.

Mr. Atkinson.

Mr. Baker

Mr. C. A. BAKER: Something has been said about the difficulty of taking a postal vote, but I think if the Institution were to get an expression of opinion of the provincial members generally on any subject by a postcard, as it did in the case of the expulsion of enemy members last year, such expressions of opinion would help very much in arriving at conclusions.

Mr. Spark

The PRESIDENT: The postal vote can still be used as a method of information, but not for an effective vote. Therefore we still feel that, while we have these means of education, namely, meetings in the country, publication in the *Journal*, and a postal vote, we still need the proxy vote finally to decide the matter.

Mr. Baker

Mr. BAKER: The President-elect spoke of giving everybody an opportunity of taking an active interest in the proceedings by this proxy vote. Applied to London I should consider those people who do not come here to vote as rather lazy and as taking only a passive interest in the Institution's affairs; the few members who have come here this evening are those who take an active interest in the Institution, and it is proposed to give the passive members an equal right by sending in a proxy. I do not, on general principles, like the idea at all, and I am inclined to support Mr. Swinton. A member would not care to solicit proxies from the general list of members because this would cost about £15 on each occasion: on the other hand, the Council with its organization could send out forms of proxy and thus swamp any proposed resolution brought up by members at a Special Meeting. I do not know whether the Council have considered another way of dealing with the matter, that is to say, taking the votes of provincial centres at those centres. Possibly the Secretary could attend, if necessary, to take such votes; these could then be totalled and the views of the Local Sections incorporated. If, on the other hand, the Council still wish this resolution to be passed, I suggest that proxy voting should be applied only in special cases by the unanimous vote of the members. Should a subject arise where it is found that proxies are wanted, the Council [illegible]

The President: With regard to the suggestion as to [illegible] here by the Companies Act. While that Act remains as it is, we cannot adopt either suggestion.

[illegible] Mr. Swinton because I think there should be proper discussion of this most important subject. If, however, the Council feel unanimously that the matter ought to be put through, I for one should not for a moment oppose it.

Mr. H. W. Clothier: I hope that this resolution will go through and that there will not be an obstruction by this comparatively small meeting of members. I will try to put the case for the Local Sections. We are a long way from town, and we cannot conveniently attend meetings in London. I have come up to London on this occasion as Chairman of the Newcastle Local Section, and it means sleeping two nights in the train, just to attend the Council this afternoon and this meeting to-night. I should like to impress upon members that we desire in the provinces to be in closer touch with London, and for this reason we attach a great deal of importance to proxy voting. It is not that we want to swamp the London vote—we could not do so if we wished. The bulk of the industrial work is done in the provinces and we are competent and worthy to have a greater share of the Londoner's privileges in the affairs of the Institution. The way is to give us a vote in matters of moment coming before a special meeting, like the particular resolution under consideration this evening.

Mr. R. A. Chattock: From what I know of the provincial members, they are only too anxious to be active in any way they can, and it is on that ground that this proposal is before the meeting to-night. They feel that it is impossible for them to take that part in the affairs of the Institution which they want to take and which they feel justified in asking that they should take. If it is possible to create any other form of machinery for attaining that end, I am sure they will be only too pleased to fall in with the suggestion of the Council, but, as the President has said, the Council have given very careful consideration to other ways and means of doing this and they have come to the unanimous conclusion that proxy voting is the only really satisfactory way of doing it. Personally I do not think that the provincial members will use proxy voting to the detriment of the Institution. They have the well-being of the Institution at heart just as much as the London members have, and it is only under very exceptional circumstances that proxy voting will probably be [illegible]

Mr. Wordingham.

[illegible] London clique. We have had strong representations from the provinces on the subject of proxy voting and something must be done—whether it is proxy voting or postcard voting is of course a different matter. I can assure members that, with all possible evidence before us, we have come to the conclusion that the only feasible way is proxy voting. With regard to Mr. Swinton's idea that there might be packing of the voting, that there might be a provincial clique trying to run the Institution, that can be done now. We cannot guard against a particular clique getting its way, because there is nothing to prevent 40 members being brought here to-night to outvote the 30 who are now present. The same thing, I admit, can happen with proxy voting, but it can also take place with postcard voting. A number of postcards may be sent out to members, but we cannot make them return them. That observation applies to the balloting papers, not one-quarter of which are returned, and the same thing happened with the postcard expression of opinion in connection with enemy members, and with the inquiries sent out asking members whether they were enemies or friends. A good deal of stress has been laid upon its being undignified for the Council to send out proxies. I do not admit that it would be undignified; but if it were, I think it is much less important that the Council should suffer in its dignity than that the large body of members should be in the undignified position of being absolutely disfranchised, and having no power whatever of voting in connection with the Institution of which they are just as much members as those residing in London.

Mr. Williams.

Mr. E. T. Williams: It seems to me that proxy voting has serious disadvantages, and if all the members were in one town I think many of us would agree that proxy voting would be wrong. But the Institution is entirely different, and I think we are justified in voting for proxy voting, because a very great majority of our members are in the provinces. The vitality of this Institution is very largely made up by members from the provinces, and therefore it is a question of accepting a small evil, proxy voting, to obtain a great good. The feeling is that there will be a certain amount of proxy voting by people who do not hear the discussion, and this is of course a point against proxy voting, but if at the same time we can get the opinion of the whole of the members, it seems to me we get nine points to the good and only one point to the bad. A development of this would be that if any important question arose the Local Sections would have their own discussions upon those matters, and they would in many cases send their Chairman or perhaps two members (pro and con) to an important discussion in London to represent the views of the Local Section, carrying with them proxies. I have great pleasure in supporting this resolution from that standpoint.

The resolution was then put and carried, 28 members voting for it and 4 against.

The meeting then terminated.

SPECIAL GENERAL MEETING OF CORPORATE MEMBERS, 14 JUNE, 1917.

(Held at the Temporary Offices of the Institution, 1 Albemarle-street, London, W. 1.)

r. Sparks. Mr. C. P. Sparks, President, took the chair at 6 p.m. and, after it had been agreed that the notice convening the meeting should be taken as read, he explained the object of the meeting, viz. to confirm the Resolution in regard to Proxy Voting passed at the Special General Meeting held on the 17th May (see page 527). He also read a number of letters and telegrams in support of the proposal before the meeting, and then formally moved the resolution.

r. elbourn. Mr. B. **Welbourn**: In rising to second the resolution I feel that I do so under a sense of peculiar responsibility, because not only do I know that I am here as the representative of the most important Local Section of the Institution, Manchester, but I have reason to believe that I am speaking for the whole of the Local Sections. At the time the postal vote in regard to alien enemies was taken, the difficulty of the position was appreciated in the provinces so keenly that I thought it right to bring before the Committee of the Manchester Local Section this question of proxy voting. I am glad to say the Committee at Manchester was absolutely unanimous. The matter was submitted to the Council, and the principle of proxy voting was also unanimously accepted by them and was referred to the Vice-Presidents' Committee for investigation in detail. Mr. McKenzie, our Chairman, was co-opted to act with the Vice-Presidents in this matter. A number of those meetings Mr. McKenzie could not attend, and I was invited to do so in his place. The Report of the Vice-Presidents was brought before the Council and was unanimously adopted. I want to-night to lay stress on the fact of the unanimity that there has been in London on the part of the Council in regard to this matter, because if this resolution is lost I want it to be known in the provinces that the Council in London are not in any way responsible for its being thrown out. The question may well be asked: Why are the Local Sections unanimous in wanting proxy voting? The reason is that we feel we are at present largely disfranchised, and that we ought not to have to give up our time and be put to the serious expense of coming to London on every important occasion to record our votes. We think it is a simple matter of justice to those who cannot attend the meetings. If there are any members here who are not in favour of proxy voting, I want to assure them that I am quite certain that, so far as the provinces are concerned, there is no unhealthy agitation behind this request. I am sure there is no wish to agitate on every possible and impossible occasion. But a great many members in the provinces do feel that they will be able to take a larger share and a greater interest in the affairs of the Institution and, to put it quite bluntly, be getting better value for their money if this resolution is passed. In saying that I do not at all wish to overlook the fact, which is very much appreciated throughout the country now, that the introduction of corporate membership of the Institution five years ago has very largely improved the status of members. In conclusion, I want to make an appeal that there shall be a unanimous vote on this subject. That will have a splendid effect on the country members, a very large number of whom are not able to keep as closely in touch with the London members and with the Council as I personally have been able to do in the last two years. As I said just now, I feel sure that proxy voting, if it goes through to-day, will be used very discreetly by the country members, and that the Council will have nothing whatever to fear from it. Mr. Welbourn

Mr. A. C. **Cramb**: With regard to this question of proxy voting, I take it, after what has been said, that all that is desired is that there should be given to every member of the Institution as far as possible an equal opportunity of having a voice in the management of the Institution. If, when the President talks of proxy voting, that is what is meant, then I believe everybody inside this room to-night, and everybody outside belonging to the Institution, heartily agree. I think at the present time the arrangements are altogether unsatisfactory. But, as far as my experience goes, proxy voting is generally associated with companies whose reputations are pretty bad, and I am very sorry to see the word "proxy" used in connection with the Institution at all. Mr. Cram

The **President**: We are really a limited company, although the word "limited" does not appear in our title owing to the fact that we are not a company trading for profit. Our meetings are governed by company law, and for that reason this particular method is used, because it is the only one permissible under the Companies Act. As to the method of using proxies, assume that a change is desired in the Articles of the Institution. Notice having been given, the meeting is held on a certain day. A certain number of days beforehand it may be possible for the members in Manchester, say, to give their proxies to their Chairman or to any Corporate Member, so that Mr. Welbourn may come to the meeting with 700 proxies. These proxies would be deposited a certain number of hours beforehand at the Institution's offices. When the meeting is held, when Mr. Welbourn speaks, instead of one member, he holds in his hands, say 700 votes, and Mr. Cramb may come along with, say, 500 votes; and the Chairman of the meeting will know that when these people are speaking they are speaking in that way. At the same time, the Council may themselves feel that they should ask for proxies, and they will know that they have 1,000 or 2,000, or whatever the number of votes is, agreeing with their views. I do not know the exact number of members at this meeting to-night, but say there are 40 who are going to determine this question; if we had proxy voting, instead of having only 40 we might have present in the room some 4,000 votes. The telegrams and letters that I have read to-night have no legal weight, although they may have a moral effect on us, but under the suggested new arrangement, instead of having only the votes of 40 members we should have the votes of, say, 4,000 members who have a direct interest in what was going to be decided. Mr. Sparks

Mr. **Cramb**: The point I want to be satisfied about is this. Are we or are we not going to take the vote out of the hands of the individual members? Are members going to be silly enough to put their voting power on any Mr. Cramb.

[illegible] other persons would probably have had at their disposal [illegible] the alteration [illegible] to come to a decision." I think that as far as possible the provincial members should be able to take advantage of their rights in any election by postal vote, which in my opinion is the proper way to do it. I think it ought to be done in that way; I do not like the idea of a large number of votes being put into the hands of a man to use as he likes; and it seems to me, at the moment at any rate, that that is practically what the proposal amounts to.

The PRESIDENT: I explained at the last meeting that a "postal vote," although it may have a moral effect, has no legal effect at all. Every member, when these resolutions are passed, will still have the right to come here in person and take part in the proceedings. At the present time if he cannot be at the meeting he is disfranchised, but by the powers contained in the resolution he will be able to transfer his vote to any corporate member able to attend.

Mr. CRAMB: I still do not like the idea. Unless that man has a signed paper from the member saying which way he wants to vote, that member is handing over to some one else discretionary powers to use his vote whichever way he likes.

The PRESIDENT: That is well known, and that is exactly what is intended.

Mr. CRAMB: In my opinion that is most objectionable. Although this is done under the guise of giving the other members of the Institution an opportunity of taking part in the proceedings, it does not actually do so. Do not think I am criticizing the desirability of altering the Articles, because I gather it is time we had them altered. But we know what has happened in the company world in regard to this sort of thing; it has been a very unsatisfactory arrangement, and the time has come to suggest to the Government that they should alter the Companies Act so that we can vote in a different [illegible].

Mr. A. GAY: I gather from the President's reply to Mr. Cramb that the proxy paper itself does not bear upon it "Aye" or "No." Is it in the discretion of the individual who holds the proxy to vote either way? Is it within the power of the original voter to delegate his vote to the proxy holder without actually stating whether he votes for or against?

The PRESIDENT: The Memorandum on Proxy Voting sent out with the notice of this meeting says: "The procedure in regard to proxy voting is as follows: At any Special or Annual General Meeting any member entitled to vote, but unable to attend the Meeting, has the right (by filling in a proxy paper) of appointing as his proxy some other person able to be present. The proxy paper need bear a penny stamp. The member cannot direct how his proxy shall vote, and the latter uses the votes entrusted to him in any way he thinks desirable." That is, one gives the proxy to a particular individual, and one may write to him and say, "I think this, that, or the other," and it is a question of whether one trusts the man to whom one gives the power to do the best he can with it. If one writes a friend and says "vote against it," and if the man uses the proxy and votes the other way he has done a dishonourable thing.

Mr. GAY: The other matter in which I am interested is this. We know that year by year the officers of the Institution are elected by a postal ballot. Can the President tell me definitely whether there is anything in the Companies Act which would extend the vote by postal ballot to the General Meetings?

Mr Sparks.

The PRESIDENT: We have power to elect our officers in that particular way, but we have not the power to change our Articles of Association in that way. The Companies Act makes no provision for changing the Articles by any such method.

Mr. Gay

Mr. GAY: The explanation which the President has made with regard to proxy voting proves that it is a most dangerous weapon—it is a two-edged one too—not only in the case of the Council but also in the hands of the members of the Institution, because one man who has a vote can go to all his friends, and, by his flowery way of talking and in his own interest, get a pocketful of proxies, and he can come and spring them upon a Special General Meeting or a General Meeting and carry everything before him. With all due respect and with every desire to give the fullest possible opportunity of voting fairly and honestly to the whole of the members of the Institution, whether in the provinces or in London, I think that this method of proxy voting, seeing that the holder of the proxy has absolute discretion and the original voter has none, is a most dangerous one. Therefore I should be very sorry indeed to see this resolution carried. If it is possible to give the members a postal vote, then each individual member would be able to express his individual opinion.

The PRESIDENT: That is not legally possible.

Mr. Gay.

Mr. GAY: I think under the circumstances proxy voting will not do. Although it may be the only thing that can be done, it will not carry out the desire of the provinces, because, as I say, it does not represent the vote of the individual; and if we allow one man to vote for 700 men it seems to me that the whole matter is getting into a state of chaos and he can do as he likes. If, on the other hand, voting cards are sent out, there is printed on the top exactly what one is voting for; the whole thing is set out and the member can think for himself; whereas with proxy voting in many cases a man would go and indiscriminately collect proxy papers and use them to suit his own interests. I do not say he would do so dishonourably, but it might not be put clearly to the members who desired to vote what he desired to vote for and in which way he desired to vote. It seems to me it is a very dangerous principle to adopt.

Mr. J. E. ROBINSON: I am speaking on behalf of the Municipal Engineers of Greater London many of whom have not been able to attend this meeting to-day. My Association particularly want me to say that they have every desire that every member of the Institution, whether in London or in the provinces, should have full opportunity for voting, but they are practically unanimously opposed to proxy voting. I want to ask the President whether eminent legal opinion has been taken which makes it quite certain that a postal vote is not possible, that is to say every member would have a definite individual vote.

Mr. Sparks.

The PRESIDENT: We have a definite legal opinion not that it is impossible but that it can have no legal effect. I have before me the Companies Consolidation Act, 1908, Mr. Sparks.

and Section 13 (1), dealing with Articles of Association, reads: "Subject to the provisions of this Act and to the conditions contained in its memorandum, a Company may by special resolution alter or add to its Articles; and any alteration or addition so made shall be as valid as if originally contained in the Articles and be subject in like manner to alteration by special resolution." A special resolution can be passed only at a meeting such as the meeting which we are now holding.

Mr. Robinson.

Mr. Robinson: I venture to say that while proxy voting is very much better than what we have had in the past, I think a direct postal vote would be better still.

Mr. Atkinson.

Mr. L. B. Atkinson: Being rather closely associated with Manchester, some members of the Manchester Local Section have asked me, knowing that I was in London and possibly might attend here to-day, to urge that in their view proxy voting is a reasonable and proper method of carrying out what everybody desires to carry out, and that it does not contain the dangers which some of our friends see. I am going to vote for proxy voting because I find that those who have most deeply studied the subject believe it to be sound. We are face to face with the fact that the Council in London and the Committees of all the Local Sections have unanimously passed this recommendation, after giving it full consideration. I think therefore that individual members, even with the best wish in the world to help the Institution, are taking rather a heavy responsibility upon themselves in trying to override this considered opinion in regard to the precise method of doing what all parties agree should be done.

Mr. Stothert.

Mr. J. K. Stothert: I assure members that the whole of the Scottish Local Section are solid in supporting proxy voting, and it is by the request of a meeting which we specially convened that I attend here to-day. I should like to make one criticism of Mr. Gay's remarks, the suggestion that if a member hands a proxy to his representative the latter might act against the member's wishes. As the President has said, that would be a dishonest act. The exercise of proxy voting in connection with companies run for profit is a different thing from the exercise of proxy voting in regard to an Institution which is run on the broad principles and the high standards which are practised by this Institution. I think we could hardly find one member who would use a proxy vote in that way; he would return it rather than use it in the opposite sense to that for which it was entrusted to him by the member. I appeal to this meeting to support the resolution, because the Scottish Local Section would be very disappointed if it were not carried.

Mr. Stot

Mr. H. H. Wright: The members of the Yorkshire Local Section are most heartily in favour of this resolution. They are quite aware as to the possible defects in proxy voting, but they feel that, even with its defects, it is better than the present system. I do not think the dangers and difficulties which have been enumerated by the various speakers in opposition to the motion are very serious. Personally, if I were deputing my vote to a member I should see that he was a member in whom I had every faith, and I am quite certain that every other member would adopt the same principle.

Mr. Wri

Mr. H. W. Clothier: The provinces want a closer touch with the Council and with the London members. They do want to be more a part of the Institution. I am sure I am right in saying that there are dozens and even hundreds of men in the provinces who would be members of the Institution if they felt the corporate spirit of it, but a man cannot feel that the Institution is part of himself when he is remote and practically disfranchised. Men in the provinces have no idea at the present time of the large amount of work which is done by the Council. Even though the Chairmen of the Local Sections are represented on the Council, it is impossible to convey to members anything like comprehensive details of work done by the Council, nor the amount of personal thought and devotion which is given by the President and the Past-Presidents to the affairs of the Institution. We feel in the provinces that proxy voting will lead to a better understanding and will enable all members to co-operate for the general welfare of the Institution and the Electrical Profession.

Mr. Clot

The motion was then put by the President and carried, 25 voting for it and 9 against.

The meeting then terminated.

BENEVOLENT FUND.

1916 ANNUAL GENERAL MEETING, 17 MAY, 1917.

Mr. C. P. Sparks, President, took the Chair at 8 p.m.

The minutes of the Annual General Meeting of the 11th May, 1916, were taken as read, and were confirmed and signed.

The Chairman moved that the report (see below) of the Committee of Management and the Statement of Accounts (see page 323) for the year 1916 be adopted. Mr. C. H. Wordingham seconded the resolution, which was then put to the meeting and carried unanimously.

On the motion of Mr. R. A. Chattock, seconded by Mr. P. Rosling, Mr. Sidney Sharp and Mr. J. Attfield, F.C.A., were re-elected Honorary Auditors.

The Chairman reported that the following Committee of Management had been elected for the year 1917-18:—

The President (*ex-officio*).

W. Duddell, F.R.S. Dr. A. Russell Sir John Snell W. B. Woodhouse W. L. Preece	Representing the Council.
G. S. Ram F. Gill C. C. Hawkins H. W. Kolle	Representing the Contributors.

and the

Chairman of each Local Section in the United Kingdom.

The meeting then terminated.

REPORT OF THE COMMITTEE OF MANAGEMENT FOR THE YEAR 1916.

Capital.

The Capital Account stood on the 31st December, 1916, [illegible]

Income.

The Statement of Accounts shows that the total receipts [illegible]:—

	£	s.	d.
[illegible] ...	[illegible]	[illegible]	[illegible]
[illegible] ...	[illegible]	[illegible]	[illegible]
[illegible] ...	118	10	6
Donations of £5 and over ...	94	15	0
[illegible] ...	[illegible]	12	6
Legacy from the late Mr. H. C. Donovan ...	[illegible]	[illegible]	[illegible]
	[illegible]	14	[illegible]

The accumulated Income now amounts to £1,833 3s. 10d., [illegible]

[illegible]

[illegible]

H. Alabaster
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

The Hon. E. Cozens-Hardy
[illegible]
[illegible] Davenport
[illegible]
F. E. Davies
W. Deacon
[illegible]
J. [illegible]
B. M. Drake
Dr. C. V. Drysdale
W. Duddell

[illegible]

K. Edgcumbe
W. V. Edwards
S. Evershed
M. Farrer
E. Garcke
F. Gill
Sir R. T. Glazebrook, C.B.
G. F. C. Gordon
[illegible]
F. E. Gripper
C. W. Gwyther
H. T. Harrison
C. C. Hawkins
W. C. C. Hawtayne
K. [illegible]
D. Henriques
[illegible]
H. Hirst
H. C. Holroyd
[illegible]
E. S. Jacob
Dr. G. Kapp
A. C. Kelly
W. T. Kerr
J. E. Kingsbury
H. W. Kolle
[illegible]
J. R. P. Lunn
[illegible]
Sir Henry [illegible], C.I.E.
E. Manville
[illegible]
J. W. Meares
[illegible]
L. B. Miller

W. M. Mordey
W. M. Morrison
W. C. Mountain
A. J. Newman
F. H. Nicholson
Col. A. M. Ogilvie, C.B.
C. Oliver
E. Parry
The Hon. Sir C. A. Parsons, K.C.B.
W. H. Patchell
C. C. Paterson
F. G. Payne
A. H. Preece
W. L. Preece
N. Prentice
H. F. Proctor
G. S. Ram
W. R. Rawlings
T. Rich
R. [illegible]
S. R. Roget
S. A. Russell
S. G. C. Russell
F. [illegible]
S. Sharp
J. F. Shipley
A. Siemens
M. [illegible]
H. A. Skelton
Sir John Snell
C. P. Sparks
C. Stewart
A. J. Stubbs
W. C. P. Tapper

ANNUAL SUBSCRIBERS—*continued.*

E. E. Tasker
W. W. Thomas
C. H. R. Thorn
A. P. Trotter
H. D. Wilkinson
W. B. Woodhouse
J. H. Woodward
C. H. Wordingham
H. E. Yerbury

DONORS.

P. F. Allan
A. H. Bate
F. E. C. Burnett
J. Burns
The Cape Town Local Centre
J. D. Dallas
The Diesel Engine Users' Association
The Electrical Engineers' Ball Committee
L. H. Euler
Messrs. W. T. Henley's Telegraph Works Co., Ltd.
H. V. Henniker
A. Howell
The Institute of Railway Signal Engineers
W. Judd
W. E. Lane
F. W. Main
Professor T. Mather
C. H. Merz
A. H. Morse
H. Parry
W. Pintner
A. J. Ramsay
E. S. Ritter
Dr. A. Russell
S. Simpson
J. L. Smith
R. T. Smith
J. K. Stothert
The "Twenty-five" Club
C. Vernier
T. C. T. Walrond

LEGACY.

H. C. Donovan

Among the larger donations received during the year were a legacy of £100 from the late Mr. H. C. Donovan, and a donation of £52 10s. from Messrs. W. T. Henley's Telegraph Works Co., Ltd.

The Committee of Management desire to acknowledge their indebtedness to these and the other donors and subscribers who have supported the Fund, but they venture once more to urge upon the members the pressing need for a more generous support of the Fund. Apart from donations the Committee will be grateful for annual subscriptions even of small amounts.

GRANTS.

Thirteen applications for assistance were received in 1916, and the Committee, after due investigation, made grants in all the cases. One grant was made of £30, four of £25, four of £10, two of £8, one of £5 and one of £4, a total of £195 for the year.

WILDE BENEVOLENT FUND.

The Capital Account stood on the 31st December, 1916, at £1,846 4s. 6d., the whole of which is invested and brings in an annual revenue of £55 17s.

The balance standing to the credit of the Income Account at the end of 1916 was £506 9s. 10d., of which £345 14s. 8d. was invested and brings in an annual income of £13 10s.

No grant was made from this Fund during the year.

INSTITUTION NOTES.

LIST OF MEMBERS.

A new edition of the List of Members of the Institution is in preparation. In view of the restrictions on the use of paper, only a limited number of copies will be printed, and each member wishing to have a copy is requested to make early written application to the Secretary.

The copies will be ready for dispatch in September.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

The following cablegram has been received from the American Institute of Electrical Engineers in reply to the message from the Institution in connection with the entry of the American Nation into the War (see page 525) :—

To Institution of Electrical Engineers,
1, *Albemarle Street, London.*

The American Institute of Electrical Engineers duly appreciates your message. We hope that the Electrical Engineers of Great Britain and of America working together in close co-operation can bring to a satisfactory conclusion the many electrical problems of the War.

MINISTRY OF MUNITIONS OF WAR.

The Institution is informed that the Ministry of Munitions is anxious to get in touch with good-class mechanical and electrical engineers, above military age and of commanding personality, who are desirous of doing work of national importance but to whom the question of salary is not of primary importance. A moderate salary and travelling expenses when on duty will be paid. Applicants should send full particulars of their experience and qualifications to I. M. Y. I., Room 458, Armament Buildings, Whitehall, S.W. 1.

PROFESSIONAL AND BUSINESS REGISTER.

The Secretary has received the following letter from the Employment Department of the Ministry of Labour :—

Employment Department,
Ministry of Labour,
Queen Anne's Chambers, S.W. 1.
[illegible]

Dear Sir,

May I call your attention to the Professional and Business Register of this Ministry, which I think might be of service to you in finding for you capable employees of the [illegible] type. Among those who have registered there is a considerable number with business, executive, and administrative experience.

I should be very pleased to arrange for an interview between yourself and those likely to suit your requirements if you could give me as full details as possible of any assistance of this kind of which you may stand in need.

(Signed) H. E. Morgan.

METRIC SYSTEM.

For the purpose of again placing on record the position of the Council in regard to the above, members are reminded that in May 1916 the President (Mr. C. P. Sparks) made the following recommendation on behalf of the Council to the Electrical Trades Committee of the Board of Trade :—

> "The use of the Metric System to be made compulsory after a reasonable period ; and during this period all trade catalogues to make use of both the British and Metric Systems."

The Council's views as above were also stated by Mr. Sparks in the discussion on the Decimal System, opened by Mr. H. Allcock, M.I.E.E., at the Institution of Civil Engineers on the 27th March, 1917.

Representations were also made to the Engineering Standards Committee by the representatives of the Institution serving on the Committee that the Electrical Section should be authorized to consider the use of the Metric System. As a result, the Committee have agreed that the Sectional Electrical Committee should have power, in submitting any new work or in bringing forward revisions of the various electrical Specifications coming under their jurisdiction, to base any measurements contained therein upon the Metric System, provided it is with the approval of the trade concerned.

TELEPHONE "CROSS-TALK" AND "SECRECY."

At the request of the Telephone Manufacturers' Association definitions of the above have been considered by the Telegraphs and Telephones Sectional Committee of the Institution, and they have been approved by the Committee and adopted by the Council as follows :—

"Cross-talk" in telephone systems is the unintentional overhearing between one circuit and another, not due to any such metallic connection as arises from accident or is effected by a user or third party. In practice the "cross-talk" may be due to disturbances arising from electromagnetic or electrostatic induction, to leakance, or to insufficient conductance, in a common portion of circuits.

"Secrecy" in telephone systems is secured by an arrangement of circuits making it impossible for a third party by any normal use of the system to cut in and listen to the conversation taking place between two users, at any rate without the knowledge of the parties conversing.

The term "secrecy" must not be confused with freedom from "cross-talk."

ROLL OF HONOUR.

(SEVENTH LIST.[*])

Killed in Action.

de Pomeroy, 2nd Lieut. N. R.	Royal Flying Corps	Student
Pilkington, Capt. S.	Leicestershire Regt.	Associate
Solomon, 2nd Lieut. L.	King's Own Scottish Borderers	Associate Member
Turton, 2nd Lieut. T. C.	Liverpool Regt.	Student

Killed.

Moore, Captain B. J., M.C.	Royal Flying Corps	Associate Member

Died of Wounds.

Ferranti, Actg. Major B. Z. de, M.C.	Royal Garrison Artillery	Student
Miller, 2nd Lieut. F. S.	Royal Engineers	Associate Member
Thorne, Captain G. S.	Royal Flying Corps	Member
Young, Actg. Major C. R. M.	Royal Garrison Artillery	Associate Member

Died.

Algar, 2nd Lieut. H.	Royal Engineers	Associate Member
Carter, Captain W. L.	Royal Engineers	Member
Dumaresq, Bt. Lieut.-Col. A. H.	Royal Engineers	Member
Smith, Orderly W. K.	Friends' Ambulance Unit	Student

MILITARY HONOURS AWARDED.

(SEVENTH LIST.[†])

C.M.G.

Simpson, Major A. F. H. S.	Royal Engineers	Associate Member

Distinguished Service Order.

Fenning, Capt. E. G.	East African Transport Corps	Associate
Iles, Actg. Lieut.-Col. F. A.	Royal Engineers	Associate Member
Ionides, Major P. D.	Middlesex Regt.	Member
Lefroy, Major H. P. T., M.C.	Royal Engineers	Associate Member
Payne, Major F. G.	Machine Gun Corps	Associate Member
Simpson, Major L. S.	Royal Engineers	Associate
Spittle, Major G. H.	Royal Engineers	Associate Member
Vignoles, Major W. A.	Lincolnshire Regt.	Member

"For conspicuous gallantry and devotion to duty during a hostile counter-attack upon the battalion of which he was in temporary command. His prompt initiative and coolness at a most critical moment enabled him to rally his men, and to bring a heavy fire upon the advancing enemy, and subsequently to organize and carry out a counter-attack with complete success."—*London Gazette*, 18 July, 1917.

Military Cross.

Barker, Captain E. A.	Royal Engineers	Member
Caparn, Lieutenant E. T.	Royal Engineers	Associate Member
Cottle, Lieutenant P. J.	Royal Engineers	Associate Member
d'Andria, Lieutenant A. V.	Royal Engineers	Associate Member

"All communications having been cut, he went out under heavy fire and mended every cable himself. By his gallant conduct he restored communications at a critical time and set a splendid example to his men."—*London Gazette*, 26 July, 1917.

Graty, Lieutenant T. R.	Royal Engineers	Associate Member

"He worked continuously for 24 hours under very heavy fire, establishing and maintaining communications."—*London Gazette*, 26 May, 1917.

Powell, Actg. Capt. C.	Royal Engineers	Associate Member
Puttick, Captain A. W.	Royal West Kent Regt.	Associate Member

Distinguished Service Cross.

Gardner, Flight Lieut. W. E.	Royal Naval Air Service	Student

"For conspicuously good work as a pilot of a bombing machine. He has taken part in 17 raids and numerous fighter patrols."—*London Gazette*, 12 May, 1917.

Military Medal.

Bruce, Lance-Corpl. A. S.	Royal Engineers	Student
Clunas, 2nd Corpl. J. F.	Royal Engineers	Associate Member
Platt, Actg. Sergt. F. C.	Royal Engineers	Graduate

Legion of Honour (Croix d'Officier).

Norman, Captain Sir H., Bart.	Special List	Associate
Stuart, Maj.-Gen. A. M., C.B.	Royal Engineers	Member

Legion of Honour (Croix de Chevalier).

Battye, Major B. C., D.S.O.	Royal Engineers	Associate Member
Lefroy, Major H. P. T., D.S.O., M.C.	Royal Engineers	Associate Member
Olver, Captain G. T. W.	Royal Engineers	Member
Stanley, Captain R.	Royal Engineers	Member

Military Order of Savoy (Cavalier).

Smith, Major T. V., M.C.	Royal Flying Corps	Member

Silver Medal for Military Valour (Italy).

Dove, 2nd Lieut. W. E. B.	Royal Artillery	Associate Member

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[*] See vol. 54, pp. 64, 447, and 674, and vol. 55, pp. 55, 193, and 325.

[†] See vol. 54, pp. 306, 518, and 674, and vol. 55, pp. 56, 193, and 325.

Mentioned in Despatches.

[illegible]	[illegible]	Associate Member
[illegible] E. F., D.S.O.	[illegible]	Associate Member
[illegible] R. C.	[illegible]	Associate Member
[illegible]	[illegible]	Associate Member
[illegible] C. H.	[illegible]	Student
[illegible]	[illegible]	Associate Member
[illegible]	[illegible]	Associate Member
[illegible] T. A. F.	[illegible]	Associate Member
[illegible]	Army Ordnance Dept.	Associate Member
[illegible] G.	[illegible]	Associate Member
Franks, Captain H. W.	Army Service Corps	Associate Member
[illegible] R.	[illegible]	Graduate
Hamilton, Lieutenant C. N. M.	Royal Garrison Artillery	Member
Hannam-Clark, Actg. Capt. H. C.	Royal Engineers	Student
Holland, Captain H. N.	Army Service Corps	Associate Member
Iles, Actg. Lieut.-[illegible]	Royal Engineers	Associate Member
[illegible] P. D.	[illegible]	Member
Langdon, Lieutenant W. C. C.	Royal Garrison Artillery	Associate Member
Laurie, Lieutenant D. S.	Royal Engineers	Associate Member
Lefroy, Major H. P. T., D.S.O., M.C.	Royal Engineers	Associate Member
Lyon, Lieutenant B. S.	Royal Engineers	Student
[illegible] A.	[illegible]	Associate Member
[illegible] A., D.S.O.	[illegible]	Graduate
[illegible] G. C.	[illegible]	Associate Member
O'[illegible] Col. H. E.	[illegible]	Associate Member
[illegible] J.	[illegible]	Associate Member
[illegible]	[illegible]	Associate Member
[illegible]	[illegible]	Student
[illegible]	[illegible]	Member
[illegible] T. N., D.S.C.	[illegible]	Associate Member
[illegible]	[illegible]	Student
[illegible]	[illegible]	Associate [illegible]
Simpson, Major L. S.	[illegible]	Associate
Sizer, Lieutenant N.	Royal Engineers	Associate Member
Smith, Lieutenant T. A.	Royal Engineers	Associate Member
Snell, Lieutenant J. B.	Royal Engineers	Student
Speir, Major K. [illegible]	Royal Engineers	Associate Member
Spittle, Major G. H.	Royal Engineers	[illegible]
[illegible] R.	Royal Engineers	Member
Stuart, Maj.-Gen. A. M., C.B.	Royal Engineers	Member

Mentioned.

[illegible] A. C.	Royal Engineers	Associate Member
Lister, Lieut.-Col. [illegible]	Royal Engineers	Member
O'Gorman, Lieut.-Col. M. J. P., C.B.	Royal Flying Corps	Member
Simpson, Major A. F. H. S., C.M.G.	Royal Engineers	Associate Member

MEMBERS ON MILITARY SERVICE.

(TWELFTH LIST.*)

MEMBERS.

Name.	Corps.	Rank.
Anderson, J. A.	Docks Directorate	Staff Capt.
Erskine-Murray, J.	R.N.V.R.	Lieutenant
Parsons, T. C.	Royal Garrison Artillery	2nd Lieut.
Preece, W. Ll.	R.N.V.R.	Lieutenant
Reid, H. S.	Royal Engineers	2nd Lieut.
Sears, A. H.	Army Ordnance Dept.	Lieutenant

ASSOCIATE MEMBERS.

Name.	Corps.	Rank.
Addey, F.	R.N.V.R.	Lieutenant
Angers, A.	South Lancashire Regt.	Lieutenant
Bedson, H.	Aeronautical Inspection Dept.	Hon. Lieut.
Black, R. T. C.	Royal Engineers	2nd Lieut.
Bowden, J.	Royal Engineers	Major
Clark, A.	[illegible]	2nd Lieut.
Cohen, B. S.	R.N.V.R.	Lieutenant
Copeland, W.	Royal Engineers	2nd Lieut.
Dudman, S.	Royal Engineers	2nd Lieut.
ap Ellis, A.	Royal Flying Corps	[illegible]
Emtage, E. L. M.	Royal Flying Corps	2nd Lieut.
[illegible] W. W.	Royal Engineers	2nd Lieut.
Gordon, A. H.	London Regt.	Cadet
Harper, E.	R.N.V.R.	Lieutenant
Hay, P. S.	Staff	Captain
Hollingworth, J.	R.N.V.R.	Lieutenant
[illegible] C. W.	[illegible]	Sergeant
Lovelace, R. E. H.	Royal Engineers	[illegible]
Montgomery, C. H.	Royal Engineers	Captain
Munday, G. W. J.	[illegible]	2nd Lieut.
[illegible] F. D.	[illegible]	2nd Lieut.
[illegible] A. H.	Royal Flying Corps	2nd Lieut.
[illegible] H. W. H.	Royal Engineers	Lieutenant

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* [illegible]

Richardson, L.F.	Friends Ambulance Unit	Conductor
Robertson, C. E.	Army Service Corps	Private
Short, E. W.	Aeronautical Inspection Dept	Hon. Lieut.
Solomon, L.	King's Own Scottish Borderers	2nd Lieut.
Taylor, S. E. W.	Royal Flying Corps	2nd Lieut.
Webb, H. J. G.	Royal Engineers	2nd Lieut.

ASSOCIATE.

Butler, J. B.	R N.V.R.	Lieutenant

GRADUATES.

Cooper, H.	Royal Naval Air Service	Warrant Officer
Daniels, J. F.	Royal Naval Air Service	Chief Petty Officer
Flanagan, F.	R.N.V.R	Sub-Lieut.
Gibbins, J.	Oxford and Bucks Light Infantry	Sergeant
Harriss, G. S.	Royal Engineers	2nd Lieut.
Houghton, S. B.	New Zealand Expeditionary Force	Corporal
Redgrave, H. C.	Royal Engineers	Lieutenant
Rowell, J. P.	Royal Flying Corps	Captain
Sahgal, S. R.	Royal Engineers	
Sild, A.	Royal Engineers	Sapper
Wakeling, A. B.	Royal Garrison Artillery	2nd Lieut.

STUDENTS.

Bassett, A. W.	Royal Field Artillery	Gunner
Bernstein, P. L.	Manchester University O.T.C.	Cadet
Bridge, A.	Royal Engineers	Pioneer
Butterworth, H.	Royal Engineers	Cadet
Claeys, W. R. E.	Belgian Army	Corporal
Cooke, H. R.	Royal Flying Corps	2nd-class Air Mechanic
Doyle, H.	Royal Engineers	Sapper
Everett, A. G.	Royal Engineers	Pioneer
Greenwood, F.	R.N.V.R.	Ord. Seaman
Lewis, E. W.	Royal Engineers	Sapper
Paul, R. B.	South Lancashire Regt.	
Payman, S.	Royal Engineers	Pioneer
Rogers, A. H. E.	Royal Engineers	Cadet
Strickland, A.	Royal Engineers	Pioneer
Wells, V. H.	Royal Flying Corps	2nd-class Air Mechanic
Wheatley, E. K.	Royal Engineers	Pioneer

PROMOTIONS, TRANSFERS, ETC., OF MEMBERS ON MILITARY SERVICE.

(EIGHTH LIST.[*])

MEMBERS.

Name.	*Corps, etc.*	*Rank.*
Bates, D.	Herefordshire Regt.	Lieut.-Col.
Carr, W. S.	Royal Garrison Artillery	Actg. Capt.
[†] Gardiner, B. C.	Royal Marine Light Infantry	Bt.Lieut.-Col.
Glendenning, S. E.	Royal Engineers	Actg. Maj.
Lonsdale, W. S.	Royal Engineers	Lieutenant
O'Gorman, M. J. P., C.B.	T.F. Reserve	Lieut.-Col.
O'Meara, W. A. J., C.M.G.	Reserve of Officers	Bt.Lieut.-Col.
Roose, F. O. J.	Royal Garrison Artillery	Actg. Maj.
Vignoles, W. A.	Lincolnshire Regt.	Actg. Lieut.-Col.
White, B. G.	Royal Engineers	Captain

ASSOCIATE MEMBERS.

Alty, J. N.	Royal Garrison Artillery	Cadet
Archer, J. O.	Royal Flying Corps	Captain
Atkinson, A. M.	Royal Engineers	2nd Lieut.
Baker, J. A.	Army Service Corps	Lieutenant
Ballard, L. W.	Royal Engineers	Lieutenant
Barnes, S. P.	Royal Engineers	Sergeant
Beer, R. G.	Royal Engineers	Lieutenant
Bellman, H.	Royal Engineers	2nd Lieut.
Bollam, C.	Royal Engineers	Actg. Capt.
Brown, T. A.	Royal Field Artillery	2nd Lieut.
Bullard, F. R.	Durham Light Infantry	2nd Lieut.
Cater, F. L.	Army Service Corps	Actg. Lieut.
Clayton, B. C.	Royal Naval Air Service	Flight Com.
Clunas, J. F.	Royal Engineers	2nd Corpl.
Collins, D. S., D.S.O.	Royal Engineers	Actg. Lieut.-Col.
Cottle, P. J., M.C.	Royal Engineers	Lieutenant
Dainty, W. R.	Royal Naval Air Service	Lieutenant
d'Andria, A. V.	Royal Engineers	Lieutenant
Dinham-Peren, A. E. H.	Royal Engineers	Actg. Capt.
Dixon, T. A. F.	Royal Engineers	Lieutenant
Dove, W. E. B.	Royal Garrison Artillery	Lieutenant
Dunsheath, P.	Royal Engineers	Actg. Capt.
Edridge, W. H.	Royal Engineers	2nd Lieut.
Ellis, T.	Royal Flying Corps	Captain
Evans, L., D.S.O.	Royal Engineers	Actg. Lieut.-Col.
Faunthorpe, C. L.	Royal West Kent Regt.	Lieutenant
French, W. W. E.	Royal Engineers	Actg. Capt.
Goulden, C. H., M.C.	Royal Engineers	Lieutenant
Hamilton, W. G.	Royal Engineers	Lieutenant
Harris, L. J.	Royal Engineers	Lieutenant
Hatch, W. A.	Royal Engineers	Lieutenant
Hayward, C. H.	Royal Naval Air Service	Flight-Com.
Henderson, H. W. W.	Indian Army Reserve of Officers	2nd Lieut.
Hill, L. D.	R.N.V.R.	Actg. Lieut.
Hodson, W.	Royal Sussex Regt.	Corporal
Hughes, P. R.	Royal Field Artillery	Actg. Maj.
Jacques, G.	Royal Flying Corps	Captain
Jeffreys, T. W.	Royal Field Artillery	Cadet
Keith, C. H.	Royal Naval Air Service	Flight Sub-Lieut.
Lambert, E. A.	Royal Engineers	Lieutenant
Lincoln, J. W.	Royal Engineers	Actg. Maj.
Lovell, W. H.	Grenadier Guards	Lieutenant
Lyons, H. M.	R.N.V.R.	Lieutenant
McGowan, C. R.	Honourable Artillery Company	Captain
Marston, G. S.	Royal Engineers	Actg. Maj.
Meredith, J.	Royal Field Artillery	2nd Lieut.
Moir, G. H.	R.N.V.R.	Sub-Lieut.
Morrow, H. E.	Royal Engineers	Captain
Morse, L. G. E.	Royal Engineers	Captain
Neate, E. P.	Royal Engineers	Lieutenant
O'Brien, H. E.	Royal Engineers	Colonel
Payne, F. G.	Machine Gun Corps	Major

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[*] See vol. 54, pp. 307, 404, 579, and 675, and vol. 55, pp. 59, 195, and 327.

[†] For service in the field.

ASSOCIATE MEMBERS—continued.

Name.	[illegible]	Rank.
[illegible]	[illegible]	Actg. Capt.
[illegible]	[illegible]	Actg. Maj.
[illegible] [illegible]	[illegible]	Captain
[illegible]	R.N.V.R.	Sub-Lieut.
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Lieutenant
[illegible]	R.N.V.R.	Lieutenant
Smeithe, A.	Royal Flying Corps	2nd Lieut.
Smith, R. M.	[illegible]	Lieutenant
[illegible]	Royal Engineers	Major
[illegible]	Royal Engineers	Actg. Capt.
Stuart, C. E.	[illegible]	Flight-Sergt.
Turner, H. E.	Royal Garrison Artillery	Lieutenant
[illegible]	[illegible]	Actg. Capt.
Vincent, J. D. A.	Leicestershire Regt.	[illegible]
[illegible]	Australian Imperial Force	Lieutenant
[illegible]	Royal Flying Corps	2nd Lieut.
[illegible]	[illegible]	Actg. Capt.
Wood, E. L.	Gordon Highlanders	Lieutenant
Woodward, E. H. E., M.C.	Royal Engineers	Captain

ASSOCIATES.

Bishop, W. J.	[illegible]	Regtl. Qmr. Sergt.
Brooks, E.	[illegible]	2nd Lieut.
[illegible], W.	[illegible]	2nd Lieut.
[illegible], F. C.	Royal Engineers	2nd Lieut.
[illegible]	London Regt.	Bt. Maj.
Marco, F. [illegible]	Royal Engineers	Lieutenant
[illegible], A.	[illegible]	Lieutenant
[illegible] [illegible]	[illegible]	[illegible]
Tucker, W. S.	[illegible]	2nd Lieut.

GRADUATES.

[illegible]	R.N.V.R.	Lieutenant
[illegible]	[illegible]	Lance-Corpl.
Booth, H. I.	[illegible]	Lance-Corpl.
Bowers, E. G., [illegible]	[illegible]	Captain
Chandler, C. K.	R.N.V.R.	Lieutenant
[illegible]	Royal Engineers	[illegible]
[illegible]	Royal Engineers	2nd Lieut.
Groom, H. R. L., M.C.	Royal Engineers	Captain
[illegible]	[illegible]	Sergeant
Laird, S. A.	[illegible]	Captain
Medforth, G. T.	[illegible]	Corporal
[illegible]	Royal Naval Air Service	Lieutenant
[illegible]	[illegible]	Staff Sergt. Mechanist
[illegible]	[illegible]	Actg. Capt.
[illegible]	[illegible]	[illegible]

STUDENTS.

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2nd Lieut.
[illegible]	[illegible]	Cadet
Bailard, F. L.	[illegible]	2nd Lieut.
[illegible]	[illegible]	2nd Corpl.
[illegible]	[illegible]	2nd Corpl.
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

STUDENTS—continued.

Name.	[illegible]	Rank.
Beavis, E. A.	Royal Engineers	Staff Sergt.
Bedford, J. T.	Royal Engineers	Corporal
Bicknell, C. R.	Royal Garrison Artillery	Captain
Billington, E. J.	Royal Engineers	Sapper
Bishop, B. L.	Royal Engineers	Lieutenant
Bolton, C. R.	Royal Engineers	Sergeant
Brooke, H.	Royal Engineers	Sergeant
Bruce, A. S.	Royal Engineers	Lance-Corpl.
Castle, J. P.	Royal Flying Corps	Lieutenant
Chalmers, J. W. P.	Royal Engineers	Actg. Capt.
Cheel, E. S.	Royal West Kent Regt.	2nd Lieut.
Cheney, E. V.	Army Service Corps	Private
Clarke, J. C.	Machine Gun Corps	Sergeant
Collver, G.	Royal Engineers	2nd Lieut.
Colston, A. G.	Royal Engineers	2nd Lieut.
[illegible], W. W.	Royal Engineers	2nd Lieut.
Craig, H. S.	Royal Engineers	2nd Lieut.
Cunningham, P. N.	Highland Light Infantry	2nd Lieut.
Devonald, N.	Royal Garrison Artillery	Actg. Capt.
Doran, W. E.	Royal Flying Corps	2nd Lieut.
[illegible], W.	Royal Engineers	Sergeant
Felix-Smith, L. E.	Army Service Corps	2nd Lieut.
Floyd, L. G.	Royal Engineers	2nd Lieut.
Furnival, J. M.	Royal Flying Corps	Captain
Gardner, W. E., D.S.C.	Royal Naval Air Service	Flight-Com.
Grose, S. J.	Royal Field Artillery	Actg. Capt.
Hannam-Clarke, H. C.	Royal Engineers	Actg. Capt.
Jackson, H. Y. V., M.C.	Royal Engineers	Lieutenant
King, L. S.	Royal Engineers	2nd Lieut.
Lawrence, F. H.	Royal Field Artillery	2nd Lieut.
Lee, J. H.	Yorkshire Regt.	Captain
Leys, H. H.	Royal Engineers	Lieutenant
Lion, B. S.	Royal Engineers	Lieutenant
Lunnon, F. C.	R.N.V.R.	Actg. Lieut.
McDougald, L. A.	Royal Flying Corps	Captain
Morgan, E. L.	Royal Field Artillery	Lieutenant
[illegible]	Army Service Corps	Sergeant
Peskett, E. G. A.	Royal Flying Corps	2nd Lieut.
Powell, C. A. W.	Royal Engineers	2nd Lieut.
Rockey, B. S. S.	Royal Flying Corps	Lieutenant
Ross, G. M.	Royal Engineers	Actg. Capt.
Rowles, A. H.	Royal Engineers	2nd Lieut.
Trouton, D. G.	Royal Field Artillery	Lieutenant
Trutch, C. J. H.	R.N.V.R.	Lieutenant
Underwood, C. L.	Royal Garrison Artillery	2nd Lieut.
Winkley, S. H.	Royal Flying Corps	2nd Lieut.
Workman, E. W.	[illegible]	2nd Lieut.

INSTITUTION STAFF.

Herring, S. V.	London Regt.	Lance-Corpl.
[illegible], C. W.	Honourable Artillery Company	Sergeant
Tillott, G.	Machine Gun Corps	Private

ACCESSIONS TO THE REFERENCE LIBRARY.

CHANNEL TUNNEL COMPANY, LTD. The Channel tunnel and the World War. 8vo. [illegible] pp. *London*, 1917

CHANNEL TUNNEL, THE. Military aspect of the question. Address by Rt. Hon. Lord Sydenham of Combe, G.C.S.I. [illegible] 8vo. 36 pp. *London*, n.d.

Kalmus, H. T., and Blake, K. B. Magnetic properties of cobalt and Fe_2Co. Part 5. [Canada, Dept. of Mines, Mines Branch]. 8vo. 49 pp. *Ottawa*, 1916

Kapp, Gisbert. The principles of electrical engineering, and their application. vol. 1. Principles. 8vo. 368 pp. *London*, 1916

Kennelly, A. E., Achard, F. H., and Dana, A. S. Experimental researches on the skin effect in steel rails. [Reprinted from the "Journal of the Franklin Institute," August 1916]. 8vo. 54 pp. [*Massachusetts*,] [1916]

—— and Affel, H. A. Skin-effect resistance measurements of conductors at radio-frequencies up to 100,000 cycles per second. [Research division, electrical engineering dept. Massachusetts Institute of Technology. Bulletin, no. 13]. 8vo. 51 pp. *Massachusetts*, 1916

Klein, A. A. Constitution and microstructure of porcelain. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 80]. 8vo. 38 pp. *Washington*, 1916

Klingenberg, G. Large electric power stations. Their design and construction, with examples of existing stations. large 8vo. 268 pp. *London*, 1916

Lake Margaret, Tasmania. The hydro-electric power works at Lake Margaret, Tasmania. [Reprinted from "Engineering," Jan. 7 and Feb. 4, 1916]. 4to. 23 pp. *London*, 1916

Lewis, W. S., and Cleary, C. J. Standardization of automobile tire fabric testing. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 68]. 8vo. 18 pp. *Washington*, 1916

McCollum, B., and Ahlborn, G. H. Methods of making electrolysis surveys. [United States, Department of Commerce, Technologic Papers of the Bureau of Standards, no. 28]. 8vo. 84 pp. *Washington*, 1916

—— and Logan, K. H. Earth resistance and its relation to electrolysis of underground structures. [United States, Technologic Papers of the Bureau of Standards, no. 26]. 8vo. 48 pp. *Washington*, 1915

Electrolytic corrosion of iron in soils. [United States, Technologic Papers of the Bureau of Standards, no. 25]. 8vo. 69 pp. *Washington*, 1914

Leakage of currents from electric railways. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 63]. 8vo. 31 pp. *Washington*, 1216

Special studies in electrolysis mitigation: iv, A preliminary report on electrolysis mitigation in Elyria, Ohio, with recommendations for mitigation. [United States, Technologic Papers of the Bureau of Standards, no. 55]. 8vo. 49 pp. *Washington*, 1916

—— and Langford, T. H. The method of constant rate of change of flux as a standard for determining magnetisation curves of iron. [From the "Proceedings" of the Physical Society of London, vol. 23, pt. 4, June 15, 1911]. 8vo. 24 pp. [*London*, 1911]

—— and Peters, O. S. Surface insulation of pipes as a means of preventing electrolysis. [United States, Technologic Papers of the Bureau of Standards, no. 15]. 8vo. 44 pp. *Washington*, 1914

Matsumoto, H. Carrying capacity of underground power cables. [Report no. 24 of the third section Electro-Technical Laboratory, Tokio, Japan]. 8vo. 160 pp. *Tokio*, 1916

Meares, J. W. Electrical engineering practice. A practical treatise for civil, mechanical, and electrical engineers, with many tables and illustrations. 3rd ed. 8vo. 663 pp. *London*, 1917

Merica, P. D. Failure of brass. pts. 2, 3. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, nos. 83, 84]. 8vo. [*Washington*,] 1916

2, Effect of corrosion on the ductility and strength of brass.
3, Initial stress produced by the "burning in" of manganese bronze.

Middlekauff, G. W., and Skogland, J. F. Photometry of the gas filled lamp. [United States, Department of Commerce, Scientific Papers of the Bureau of Standards, no. 264]. 8vo. 20 pp. *Washington*, 1916

An interlaboratory photometric comparison of glass screens and of Tungsten lamps, involving color differences. [United States, Dept. of Commerce, Scientific Papers of the Bureau of Standards, no. 277]. 8vo. 22 pp. *Washington*, 1916

—— Mulligan, B., and Skogland, J. F. Life testing of incandescent lamps at the Bureau of Standards. [United States, Dept. of Commerce, Scientific Papers of the Bureau of Standards, no. 265]. 8vo. 30 pp. *Washington*, 1916

Murray, D. Printing telegraphy: high speed and low speed. Metal storage transmitters. [Reprinted from the "Telegraph and Telephone Journal," Feb., 1916]. 8vo. 19 pp. [*London*, 1916]

Nottage, W. H. The calculation and measurement of inductance and capacity. 8vo. 137 pp. *London*, [1916]

North-Eastern Railway. The electrification of the Sheldon-Newport Branch of the North-Eastern Railway. [Reprinted from "Engineering," May 26th and June 2nd, 1916]. 4to. 16 pp. *London*, 1916

Porter, J. B., *and others.* Weathering of coal. An investigation of the coals of Canada, with reference to their economic qualities: As conducted at McGill University, Montreal, under the authority of the Dominion Government. [Canada, Dept. of Mines, Mines Branch]. Extra volume, Supplementing Report no. 83. 8vo. 229 pp. *Ottawa*, 1915

Rankine, W. J. M. A manual of applied mechanics. 6th ed. 8vo. 662 pp. *London*, 1872

A manual of civil engineering. 9th ed. 8vo. 798 pp. *London*, 1873

Raphael, F. C. The localisation of faults in electric light and power mains. With chapters on insulation testing. 3rd ed. 8vo. 218 pp. *London*, [1916]

Rennie, J. A paper on electric meters. [The Association of Supervising Electricians]. sm. 8vo. 29 pp. [*London*], 1916

Richardson, O. W. The emission of electricity from hot bodies. 8vo. 312 pp. *London*, 1916

Rittman, W. F., Dutton, C. B., and Dean, E. W. Manufacture of gasoline and benzene-toluene from petroleum and other hydrocarbons. [United States, Dept. of the Interior, Bulletin 114]. 8vo. 286 pp. *Washington*, 1916

[illegible]

—— and Vinal, G. W. Summary of experiments on the Silver Voltameter at the Bureau of Standards, and [illegible] Standards, no. 285].

[illegible]

—— [illegible] electrolysis mitigation, no. 2. [United States, Dept. of Commerce, Technologic Papers of the Bureau of [illegible]

—— [illegible] mitigation, pts. 1, 3. [United States, Dept. of Commerce, Technologic Papers of the Bureau of [illegible]

[illegible]

Savage, H. A paper on modern power cables. [The Association of Supervising Electricians].

[illegible]

Schlink, F. J. Liquid-measuring pumps. [United States, [illegible] Bureau of Standards, No. 81.]

[illegible]

Sheppard, E. R. Modern practice in the construction and maintenance of rail joints and bonds in electric railways. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 62].

[illegible]

Sherley-Price, H. Depreciation of works and machinery, its causes, effects, and treatment.

[illegible]

[illegible] des Ingénieurs Electriciens d'Angleterre et de France, [illegible]

[illegible]

Spon, E., and F. N., Ltd. Spon's electrical pocket-book. [illegible]

[illegible]

Wire and sheet gauge tables. A metal calculator and ready reckoner for merchants, and for office and shop use, in Sheet, Plate, and Rod mills and forges.

[illegible]

[illegible]

Stroude, F. An accurate examination of the Steinmetz index for transformer iron, stalloy and cast iron. [illegible]

[illegible]

[illegible]

Trotter, A. P. Presidential Address. [The Association of Supervising Electricians].

[illegible]

Uhler, H. S., and Browning, P. E. On the electrolysis and purification of gallium. [From the American Journal of Science, vol. xlii. November, 1916].

8vo. 10 pp. *n.p.*, 1916

[illegible] des charges relatif aux câbles sous plomb armés et à leurs accessoires, destinés à supporter des tensions supérieures à 2,000 volts. sm. 8vo. 15 pp. *Paris*, 1912

United States: Dept. of Agriculture, Forest Service. Water-power projects, telephone, telegraph, power, transmission lines on the National Forests. Regulations of the Secretary of Agriculture and instructions regarding applications for permits for water power projects under the Act of Feb. 15th, 1901, and for easements for telephone, telegraph, and power transmission lines under the Act of March 4, 1911.

sm. 8vo. 90 pp. *Washington*, 1915

United States: Dept. of Commerce. Circular of the Bureau of Standards. nos. 6, 48, 52, 54, 60, 61, 62.

[illegible]

[illegible]

tive criticism. [2nd ed.]

60, Electric units and standards.

[illegible]

62, Specifications and methods for testing soaps.

United States: Dept. of the Interior. Water Powers of Canada. [Dominion Water Power Branch, Ottawa, Water resources paper, no. 16].

[illegible]

Vallauri, G. Sul funzionamento dei tubi a vuoto a tre elettrodi (audion) usati nella radiotelegrafia. [Estratto dal Giornale L'Elettrotecnica].

[illegible]

[illegible] Statistik der elektrizitätswerke in Deutschland. Herausgegeben [illegible]

Vinal, G. W., and Bates, S. J. Comparison of the silver and iodine voltameters and the determination of the value of the Faraday. [United States, Dept. of Commerce, Scientific Papers of the Bureau of Standards, no. 218. Reprinted from Bulletin of Bureau of [illegible]

Waters, C. E. Data on the oxidation of the automobile cylinder oils. [United States, Dept. of Commerce. Technologic Papers of the Bureau of Standards, [illegible]

[illegible] and other properties of concretes as affected by materials and methods of preparation. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 58].

[illegible]

OBITUARY NOTICES.

HARALD BILLE met his death under tragic circumstances on the 19th August, 1916, whilst travelling from Norwood Junction to Victoria Station. He was the son of a Danish clergyman and was born on the 25th May, 1879. In 1902 he took the degree of Civil Engineer at the Polytekniske Laeranstalt at Copenhagen, and after a short time spent in the designs department of Burmeister and Wain, the well-known shipbuilders, he entered the technical branch of the Great Northern Telegraph Company at Copenhagen in August 1902. Two months afterwards he was transferred to Newcastle, and six months later to London. On the 1st May, 1904, he was appointed an engineer's assistant at Copenhagen, where for the next few years his work was chiefly connected with the instrument factory, and this gave him full opportunity of developing his mechanical ability. On the 1st March, 1907, he was promoted to assistant engineer and transferred to Shanghai. He remained in the Far East till the end of 1909, during which time he paid visits to the various stations of the company out there and conducted experimental work, which enabled him to become thoroughly acquainted with Great Northern practice. For about nine months he acted as engineer during the absence of Mr. Schönau. He returned to Copenhagen at the end of 1909, and from May 1910 he was, in conjunction with Mr. Albertus, placed in charge of the technical department there. During the following years he was constantly at work upon a receiving perforator, which he eventually succeeded in perfecting to such a degree that Mr. Creed, who some years earlier had invented a similar instrument, offered him a partnership in his business. This Mr. Bille accepted and, in consequence, resigned his position in the company on the 1st March, 1912. Since the outbreak of War he devoted himself with unflagging energy to the work of producing munitions. He was heart and soul with the Allies and had applied for letters of naturalization so that he might offer his services to the War Office. As a telegraph engineer he stood in the front rank. His breadth of knowledge, his logical orderly mind, and his quiet and gentle bearing endeared him to all telegraph men with whom he came in contact. He had to an unusual degree the capacity of inspiring affection from all those who were subordinate to him. He leaves a widow and three children to mourn his loss. He was elected a Member of the Institution in 1914. H. H. H.

SYDNEY THORNTON DOBSON was the fifth son of the late Henry Holmes Dobson, of Piccadilly, and was born in London on the 20th January, 1866. He was educated at St. Paul's College, Stoney Stratford, and at King's College School, London, and studied at the School of Electrical Engineering, Princes-street, Hanover-square. After serving for 12 months with Messrs. Edmunds and Goolden, he was apprenticed in 1884 to Messrs. R. E. Crompton & Co., passing through all departments of their works, and later acting as second engineer at their electric lighting station at Tilbury Docks. In 1887 he joined the electrical staff of the Imperial Continental Gas Association, and as senior assistant had charge of their central station in Vienna for the electric lighting of the Court Theatres, which was at that time the largest example of the supply of electricity at low pressure and with storage batteries. In 1889 he returned to England, and was appointed chief engineer to the St. James' and Pall Mall Electric Light Company, then just commencing supply, and he occupied that position at the time of his death. In 1900, when the Central Electric Supply Company was formed for the supply of electricity in bulk, he was associated with Sir Alexander Kennedy as joint engineer of the scheme. His professional life was entirely devoted to the interests of these electric supply undertakings, and their success is in no small measure due to his high technical skill and sound judgment. He was accidentally drowned through a fall from his motor yacht in Poole Harbour on the 5th July, 1916. Though he never cared to take the prominent position in public to which his abilities and force of character entitled him, he was known and appreciated by a large circle of friends and his loss will be deeply regretted by them, as well as by the even larger circle of those who from time to time had the advantage of his ready assistance and advice. He was elected a Member of the Institution in 1889, and served on the Council from 1902 to 1905.

WILLIAM ELLIS, F.R.S., was born at Greenwich in the year 1828. At the early age of 13 years he entered the service of the Royal Observatory, as a member of the computing staff then engaged upon the reduction of the important series of observations of the moon, made in the years 1750 to 1830. After the completion of these reductions, he received the appointment of junior assistant on the Observatory staff in 1853, and two years later was placed in sole charge of the time signals, and control of the Time Department. In that capacity the development of the system for the distribution of correct time throughout the country claimed a considerable share of his official duties, and the system was gradually brought to a state of perfection. The scheme which he developed, in concert with the Post Office as distributing agents, was fully described by him in *Nature* in 1876, and afterwards reprinted as an Appendix to the Greenwich Volume for 1879. As an extraneous portion of the work connected with his department, he took part in the telegraphic work involved in the following longitude determinations:—Edinburgh, 1857–1858; Valentia, 1862; Glasgow, 1865; and the observing stations included in the Transit of Venus expedition of 1874. At the end of the year 1874 he was appointed to succeed Mr. Glaisher as Superintendent of the Magnetical and Meteorological Department at the Royal Observatory. His knowledge of that department was then confined to occasional inspections of the adjustments of the earth current galvanometers and wires, and regular attention to the standard sidereal clock. On taking [illegible] he turned his attention [illegible] between the [illegible] period and magnetic variations which [illegible] but had not yet [illegible] scientific examination. For this task he employed the magnetic records which had been accumulating at the Royal Observatory since 1848. He pursued his investigation with great thoroughness and completed his task by the year 1879, when he communicated the [illegible] to the Royal Society which is published [illegible] He subsequently expanded his research to include all the results of the observations for the 56 years 1841–1896, and the final results obtained in this important inquiry are given in a paper [illegible] of the *Proceedings* of the Royal Society. The relation between the sun-spot frequency and the magnetic elements is clearly shown in both of these investigations. Many other magnetic papers followed at brief intervals contributed either to the Royal Society or to the Royal Astronomical Society, and are published in the records of those Societies. As relating to the [illegible] he contributed many abstract papers to the Royal Meteorological Society during his term of office as President of that Society in the session 1887–1888. At the end of the year 1893, having completed his full term of service, he retired from official life at the age of 65 years, but still continued to interest himself in scientific work until he became disabled from physical exertion by increasing age and gradual loss of sight. He [illegible] December, [illegible] He was elected a Member of [illegible]

W. C. N.

ALBERT HARRIS HOWARD, who died on the 1st November, 1916, was born at Knightsville near Providence in Rhode Island on the 11th July, 1862. He was the son of Mr. Albert C. Howard, a banker in Providence, who was Lieutenant-Governor of the State of Rhode Island and [illegible] the Civil War, was an officer in the United States Army. The family, descended from the historic House at Arundel, migrated to America in the year 1660 and settled in Connecticut, and Albert Howard was born on the estate acquired by his great-grandfather in Rhode Island in the year 1705. From early years Mr. Howard [illegible] as well as [illegible] the Brown University, where he found more scope for his mathematical and [illegible]

[illegible] Engineering from the practical side Mr. Howard entered the [illegible] country. He held the post of Chief Engineer to the [illegible] the London manager for Messrs. W. T. Glover & Co. In 1899 he became secretary of the Cable Makers' Association, a post which he held to the end of his life, and to whom his death is a severe loss, for his duties often involved very difficult and delicate matters to negotiate and adjust; but, by his exceptional tact and unfailing amiability, he won the esteem and affection of all the members of the Association as expressed in a resolution passed by a full meeting of that body [illegible] after his death. They could not but appreciate his loyalty and devotion to his duties which he so successfully performed, although during the greater part of his secretaryship he was a great sufferer from the painful complaint which brought about his end; and they could not but admire the cheerfulness and true heroism with which he bore his illness.

He was elected a Member of the Institution in May 1896, having been proposed by Mr. Henry Edmunds and supported by the late Sir William Preece, F.R.S., the late W. F. Goolden, and the late H. E. Harrison. It does not appear that he contributed any papers to the Institution, but he took part in several discussions at the meetings, notably on Mr. R. E. Crompton's paper on "The Institution Wiring Rules" in January 1899, and he served on the Committee on Copper Conductors in 1900.

He had a remarkable gift for invention; and, but for his illness which affected so many years of his life, there can be little doubt that he would have taken a very high position in his profession. He was the inventor of the "Howard Conduit" or trough for carrying electrical cables which acted as an economical protection for underground conductors as well as an insulator. He was also the designer of the "Plion" system of lighting street lamps and of a method of armouring cables.

Those who were privileged to know him when he first came to this country, and for some years after until his health broke down, will never forget his bright magnetic influence with young and old, his fascinating personality, and the original and inimitable college songs with which he would occasionally delight his friends; but perhaps the true greatness of his character displayed itself still more during the last few years of his life, for in all his suffering, which at times was very great, he maintained the most heroic and unselfish cheerfulness, doing everything in his power to make life bright around him. Truly by his death a most lovable character has gone from our midst, and the world and the profession are the poorer for his loss.

He was a very accomplished chess-player, his clear mind and powers of concentration standing him in good stead in this game. The writer of this notice has more than once seen him play five games simultaneously, and win [illegible]

He married a daughter of Mr. William Harris of Wavenden, Bucks, who survives him with two children—a son, at present engaged on scientific work in the Air Department of the Admiralty, and a daughter.

C. W. C.

GEORGE KEITH was [illegible] of the late [illegible] was born in 1846. He was educated at the Aberdeen Grammar School and Aberdeen University, after which he was apprenticed to the engineering business and went through the engineering course at Glasgow University under the late Professor

Rankine. For several years he was on the staff of Sir William Thomson (afterwards Lord Kelvin) and Professor Jenkin, consulting engineers for the construction and laying of submarine cables on the coast of Brazil, and he received from the Emperor Pedro II the order of "Cavalliero da Ordin da Rosa." He was afterwards for a considerable time resident in Cuba, where he held the position of manager and engineer of the Cuba Submarine Telegraph Company. From 1892 until his death, which occurred on the 22nd August, 1916, following an operation, he was director and engineer of the company in this country, and latterly its chairman. He was also chairman of the Chili Telephone Company, chairman and managing director of the Amazon Telegraph Company, and a director of the River Plate Telephone Company. He was elected a Member of the Institution in 1878.

SIR HIRAM STEVENS MAXIM was born in Maine, U.S.A., on the 5th February, 1840. He served an apprenticeship with a firm of coachbuilders, and after spending a short time in the machine works of his uncle obtained an appointment as foreman at an instrument factory at Boston, subsequently going to a firm of shipbuilders. About this time he commenced to take out a number of patents in connection with illumination by gas and for engineering and electrical apparatus. He was one of the first to appreciate the possibilities of electric lighting, and claimed to have invented in 1878 the first carbon glow lamp. The United States Electric Lighting Company was formed about this time to take over and work his electric lighting patents, which included several systems of arc lighting. Shortly afterwards, in 1881, he turned his attention to firearms and developed the automatic gun with which his name was always associated, and a smokeless powder. In 1896 the company manufacturing this gun were taken over by Messrs. Vickers, who a year later changed their title to Messrs. Vickers, Sons & Maxim. Sir Hiram was one of the pioneers of mechanical flight in this country and in the early days his experimental machines aroused great interest. The honour of knighthood was conferred on him in 1901. He died on the 24th November, 1916. He was elected a Member of the Institution in 1898.

D. MONNIER, who died on the 9th December, 1914, was born at Odessa of French parents, and was educated at the Ecole Centrale. In 1885 he was appointed engineer to the Gas Company at Marseilles, a position which he held for many years, and he was responsible for the installation of a modern gas-supply system in that city. A sedentary occupation did not, however, appeal to him, and being of an investigating turn of mind, he joined in 1879 the Paris-New York Transatlantic Telegraph Company and was responsible for the construction and laying of cables and for the control of the Company's stations in France, England, and America—a very different rôle from that of supplying gas in Marseilles. It was, however, the International Electrical Exhibition of Paris in 1881 which showed him his real bent, namely, the industrial applications of electricity. The electric glow lamps shown at that exhibition foreshadowed a complete change in methods of lighting. The old and powerful gas companies were afraid of what such lamps might lead to, and some of them united to form a research laboratory where the possibilities of the new rival could be investigated. They had no hesitation in placing in charge of this laboratory Monsieur Monnier, who was both a gas and an electrical engineer. They could not have made a better choice. In 1884 the English Continental Gas Company requested him to undertake the lighting of two theatres and the erection of a power station to supply them, which at that date was an enterprising scheme. The same year the Ecole Centrale decided to create a special department for the teaching of electricity and its industrial applications. Monsieur Monnier was appointed head of the department, a position which he held until his death. This was the first occasion on which electrical engineering had been a recognized course in a large French technical school. When one looks back now at those electrical courses of 1884–1885 which comprised only 20 lessons, it is amusing to see what a small number of lessons were sufficient to instruct an engineer in the general theory of electricity and magnetism, electrical measurements, continuous and alternating-current machines, transformers, lighting, photometry, electrical transmission and distribution, batteries, galvanoplasty, and even telegraphy. When one turns to the last course of lectures given by Monsieur Monnier in 1913–1914, at the age of nearly 80—a course of 50 lessons, including the design of machines, overhead lines and distribution of alternating currents, with or without the use of the method of imaginary quantities—one can truly admire the remarkable youthfulness of spirit of a man who, at an age when most people begin to forget the little they have known, kept himself thoroughly informed as to all that was published on his subject in France and other countries, and continually introduced into his lessons the results of the most recent researches. He had a charming personality and his good humour made him one of the most popular of the professors, and those who knew him will always remember him with affection. More than 6,000 engineers now scattered throughout the world were educated by him, and more than once during recent years he has seen, seated on the forms before him, the sons of those whom he had taught in the early days. Throughout his long career Monsieur Monnier took part in all the important technical commissions; he was also one of the judges at all the electrical exhibitions and he received numerous honorary distinctions. He was elected a Foreign Member of the Institution in 1880 and became a Member in 1911.

G. S.

JOHN JAMES RUDALL OVERTON was appointed after a course of training at Cooper's Hill Engineering College an assistant superintendent in the Indian Telegraph Department in October 1893 and rose to the rank of superintendent in July 1909. On the amalgamation of the Telegraph Department with the Post Office of India he was appointed Deputy Postmaster-General in the Province of Bihar and Orissa in April 1914. He retired from the service in June 1915. He was elected an Associate Member of the Institution in 1907 and a Member in 1913.

JULIUS POSSMANN, who died at Sierre (Switzerland) on the 2nd October, 1916, was a Member of the Institution since 1872, and was thus one of the oldest, of whom very [illegible]. He was born at Cologne in [illegible], [illegible] of railway engineers and contractors, where, considering his years and opportunities, he acquired a creditable smattering of mechanical knowledge. In 1861 he came to London and at once obtained employment in the Foreign Gallery of the old Electric and International Telegraph Company (then under Mr. H. C. Fischer), where his knowledge of German, French, and English was appreciated. The idea of connecting the Mother Country with her Indian dependencies was a very old one, and after the Mutiny of 1857 it was seen to be a matter of urgent necessity. In 1860 the Red Sea cables were laid, but, owing to imperfect manufacture and careless laying, they failed, one section after another, in a very few months. These failures gave a great set-back to submarine cable enterprise, and it was not until after the return of the Red Sea repairing expedition of 1862, under Sir Charles Bright, that the Government would consent to any scheme of telegraphic communication between England and India. Towards the end of 1862, Colonel Patrick Stewart, R.E., returned from a special mission to Persia, the object of which was the establishment of a line of telegraphs along the Mekran Coast, the Persian Gulf, and the Turkish dominions. His report was so satisfactory that the Government decided to commence the work at once. Colonel Stewart was appointed to superintend the scheme on behalf of the Government, while Sir Charles Bright and Mr. Latimer Clark were appointed engineers and electricians under whose sole supervision the cable was to be manufactured, conveyed to destination, and finally laid. The manufacture was commenced at Messrs. Henley's Works, Woolwich, in February, 1863, and the total length of nearly 1,500 miles was completed by the middle of October in the same year. Meanwhile, Dr. Esselbach was appointed Director of the new department and was charged with the duty of selecting the scientific and clerical staffs. Amongst the latter Mr. Possmann had the good fortune to be chosen as first-class cable clerk on the 11th August, 1863; and he sailed for India early in the following month. Within three years, owing to deaths and resignations in the superior staff, he was promoted to the rank of Assistant Superintendent on the 5th September, 1866. On the 1st January, 1869, he was appointed Construction Superintendent, and with three other officers surveyed and marked out the route for a new landline between Gwadur and Jask (Mekran Coast). In the course of this work, through a wild and little-known country inhabited by turbulent people, these officers were opposed and obstructed at every step by the local chiefs, who regarded the telegraph as the work of Shaitan (the devil); but with tact, patience, and a judicious use of baksheesh (the silver key) all difficulties were overcome. On return to headquarters from this arduous expedition in the very hottest season, Mr. Possmann was promoted to Station Superintendent (23rd August, 1869). In the following autumn an additional cable (Hooper's india-rubber) was laid down between Jask and Bushire. The operation was carried out without a hitch under the personal supervision of Mr. Latimer Clark and Colonel Bateman-Champain, then the Director-in-Chief of the Department. Lieutenant Stiffe, late Indian Navy, directed the course on board the *Dacca* and prepared the cable charts, while testing operations were in the hands of Messrs. Herbert Taylor (of Mr. Clark's staff), Possmann, and Melhuish. In those far-off days, and amongst the unruly peoples who inhabited the Mekran Coast, the telegraph officer was more than a pioneer of science. He was expected always to be a pattern to the natives around him, and often his tact and firmness in emergencies were put to a severe test. Mr. Possmann was chief actor in at least one such emergency. On the retirement of Sir Henry Mance on the 23rd December, 1886, Mr. Possmann was appointed Engineer and Electrician, and finally, on the 1st April, 1893, he became head of the department as Director, with *ex officio* magisterial powers along the Mekran Coast. For the last few years of his service he was (in addition to his telegraph duties) President of the Karachi Municipality, and Chairman of the Harbour Board, Manora. He retired on pension on the 19th February, 1897, after nearly 34 years' service, and although many of these years were spent in very trying climates, such as Gwadur (Mekran Coast), Bushire (Persian Gulf), and Fao (Shat-el-Arab), he enjoyed always the best of health. Soon after his retirement, however, symptoms of heart trouble began to show themselves, and, although seldom ailing, he had to be careful. He therefore lived very quietly, spending his summers in England and wintering abroad, for the first few years at Montreux, then for 10 years in succession in Egypt, and for the last two winters at Territet in Switzerland. He was on his way to this place for his third winter when he was taken ill at Sierre and in a few hours died (of heart failure) without pain and almost without warning.

J. J. F.

JOHN RICHARD PREECE, C.M.G., was born at Carnarvon, North Wales, in 1843. He was the youngest son of R. M. Preece of that town and brother of the late Sir William Preece, K.C.B., and of the late George Edward Preece. He was educated at a private school at Fulham and at the Imperial College, France. He afterwards joined his eldest brother's staff, who was then a divisional engineer of the Electric Telegraph Company and was stationed at Southampton. In 1868, on the formation of the Indo-European Telegraph Department, he obtained an appointment as assistant traffic manager and was sent out to Persia. From 1868 to 1891 he was connected with the Indo-European telegraphs and, except for occasional leave spent in this country, lived entirely in Persia, travelling very largely in that country. In 1879 a paper written by him was read before the Society of Telegraph Engineers on "Telegraphs in Persia." He was also Local Honorary Secretary to the Society in Persia. He retired from the telegraph service as superintendent in 1891 and was then appointed British Consul at Ispahan. The following year he became Consul for the Governorships of Ispahan, Yezd, Gulpaigan, and Konsar, the Province of Irak, and the districts of Cheharm-Mahal and Feridan. Later on the Bakhtiari territory was also included. He received his C.M.G. in 1899 and was promoted to Consul-General in 1900. He retired in 1906, having made his final journey to the Bakhtiari country the previous year when he was successful in obtaining the concessions from the Bakhtiari chiefs for the working of the oil-fields. From 1906 to 1917 he lived quietly in London, interesting himself mainly in Persian affairs.

He was an excellent Persian scholar, and thoroughly understood the Persian character, Persian policy, and diplomacy. He was also a noted collector of Persian carpets, china, and curios. He married in March, 1916, Mary Isobel, the daughter of Mr. D. Graham Allardice, and widow of Mr. J. Duncan, and he died on the 25th February, 1917, aged 73. He was elected a Member of the Institution in 1872. L. P.

JOHN RENNIE, born at Ayr in 1850, and educated at a Free Church school, began his training in large shipyards at Glasgow. When 26 years of age he entered the University of Glasgow and gained the Thomson Experimental Scholarship in physics. In 1881 he became secretary and private assistant to Sir William Thomson, and for nine years worked on the development of the Kelvin electrical measuring instruments, and helped with many of the researches which were being conducted. If ever a great man had a faithful disciple who felt it an honour to carry on part of the results of his master's life, with his ideals of scientific truth and scrupulous accuracy, here was one. In 1890 he was appointed electrician of the Board of Trade Electrical Standards Laboratory, which seemed likely to become an establishment of some importance. But it met with so much official discouragement and restriction that he never took the place in the scientific and engineering world that was his due. During the 27 years in which the Laboratory was under his charge he proved that the Kelvin balances and electrostatic voltmeters were not only worthy of the original requirements, but that they have been capable of those much higher degrees of precision which are necessary at the present day. In the early days of the Board of Trade Electrical Standards Laboratory Mr. Rennie working under Major Cardew compared the various standards and sub-standards, and minutely investigated the instrumental errors, and kept records of the histories of the important apparatus. When, with the development of electrical engineering, three-phase working opened a branch of work which the Kelvin instruments did not directly cover, he kept himself well abreast of the principles of three-phase measurement. When it became necessary to procure suitable wattmeters, he was very exacting in his requirements and expected more from the instruments than was easily provided. Perhaps the most important work of his life was expended on electric meters. The fact that notwithstanding the inadequacy of legislation with regard to meters so little trouble has been experienced, that such excellent meters are in use, and that so few are ever disputed, is the outcome of his incessant work on the subject. With his unique knowledge of the construction of electric meters he was able to point out to those who submitted types for official approval defects which would show themselves after prolonged tests. This approval was coveted not only by British but by foreign makers, and so thorough were his criticisms that gradually nearly all the meters in use were of the approved types. He was a retiring man personally unknown to many engineers but well appreciated by those few who had to deal with him. He had high ideals in human affairs as well as in science. When some verification had been made with six-figure accuracy, he used to say, "The 'Old Man' would have liked that." He died after a month's illness on the 19th February, 1917. One of his sons was killed in action in the fourth month of the War, another is in the Royal Naval Division abroad, and the third has a commission in the Royal Naval Air Service. Mr. Rennie leaves a widow and two daughters. He was elected a Member of the Institution in 1890.

A. P. T.

JOHN GRAY SCOTT was educated at Hillhead High School, Glasgow, and at the Glasgow and West of Scotland Technical College, afterwards acting as assistant to Professor Jamieson. He was appointed Borough Electrical Engineer at Whitehaven in June 1899, and to a similar position at Leith a year later. In April 1902 he was appointed Borough Electrical Engineer of the Corporation of Croydon where he was responsible for a considerable extension of the works. In February 1904 he was appointed Chief Engineer and General Manager of the Hong-Kong Railway, and occupied this position for five years. On his return to England he was for a time attached to the staff of the late Sir Clifton Robinson. For the last few years he was Professor of Electrical Engineering at the Robert College, Constantinople, and he died on the 12th July, 1916, from electric shock, through coming in contact with high-tension switchgear at the College. He was elected an Associate of the Institution in 1900, an Associate Member in 1902, and a Member in 1906. A. C. C.

SIR JAMES SIVEWRIGHT, K.C.M.G., was born in 1848 at Fochabers, N.B. He studied at Aberdeen University and obtained his M.A. degree in 1866. In 1868 he was selected as a probationer for the Indian telegraphs and was sent to the late Sir William Preece for practical experience. He later joined Preece's staff as a permanent official at Southampton when he was with the Electric and International Telegraph Company. On the transfer he became superintendent of a section in Preece's division. Subsequently, in 1876, he was for a short time Acting Secretary to the Institution when this was the Society of Telegraph Engineers and Electricians, of which he was elected a Member in 1871. In 1875 he read a paper on "Batteries and their Employment in Telegraphy" before the Society. In 1877 he went to South Africa to report on the telegraphs, and remained there as general manager to the Government telegraphs. In 1879 he wrote a second paper for the Institution on the "South African Telegraphs." He gradually became interested in politics, being much associated with Cecil Rhodes, and in 1885 he gave up the telegraph service. From 1890 to 1892 he was Commissioner of Public Works and a member of the Cape Ministry, and again from 1896 to 1898. He retired from South Africa in 1899 and came back to this country, though still retaining many interests in South Africa. He purchased Tulliallan Castle, where he lived chiefly, but he occupied himself with various public companies and was chairman of the Imperial Cold Storage Company, operating in South Africa, and Chairman of the Aluminium Corporation, which had a large water-power station in North Wales and works at Hebburn. He was also a director of the Bath Electric Tramways Company and other companies. He was joint author with the late Sir William Preece of the standard book on "Telegraphy." He was a genial Scotchman, and an excellent speaker at public meetings. L. P.

WILLIAM STANLEY (Jun.) was born in Brooklyn, N.Y., on November [illegible] 1858. On leaving college he found employment for a short time with a firm of telegraph instrument manufacturers. He then started a nickel-plating business, but soon disposed of this and became an assistant to Sir Hiram Maxim. In 1880 he joined the [illegible] of Mr. Edward Weston. Two years later he started a small laboratory of his own in Englewood, N.J., where he carried out experiments on storage batteries and on [illegible] transmission of power. In 1884 he entered into an arrangement with Mr. George Westinghouse which resulted in the formation of the Westinghouse Electric Company. In order to obtain funds to carry out further experiments he subsequently sold the greater part of his shares in the Company and designed and constructed an experimental alternating-current supply plant at his laboratory at Great Barrington, Mass. In 1886 the Company undertook to manufacture the transformers and generators which he designed, and the first alternating-current plant equipped by the Company was started at Buffalo towards the end of that year. His subsequent inventions included the auto-transformer, various types of alternating-current generators and motors, an induction wattmeter, and apparatus for neutralizing induction on telephone lines. In 1890 the Stanley Electric Manufacturing Company was formed at Pittsfield, Mass., which was afterwards absorbed by the General Electric Company. At the time of his death which took place at Great Barrington, Mass., on the 14th May 1916 he was connected with the latter Company. He was elected a Foreign Member of the Institution in 1892 and a Member in 1911.

HENRY BERNARD STONE was born in 1877 and received his electrical training at Brooklyn, U.S.A. In 1900 he was appointed resident electrical engineer to the Guildford Electricity Supply Company and superintended the erection of a new power station and the reorganization of the plant. During the South African War he served with the Electrical Engineers (R.E.) Volunteers for a period of one year. On his return to this country in [illegible] he became [illegible] manager to Messrs. [illegible] Dawson and Co. In 1905 he was appointed manager of the power and supply department of the Rangoon Electric Tramway and Supply Company, a position which he held for 4½ years. After six months in business on his own account in Calcutta, he became resident engineer in charge of the re-erection and maintenance of the Jammu [illegible] installation. In March [illegible] he was appointed chief electrical engineer of the Jhelum power installation at [illegible], Kashmir. He later became [illegible] manager and [illegible] engineer to the Lahore Electricity Supply Company, a position which he held until his death, in September [illegible]. He was elected an Associate Member of the Institution in 1909 and a Member in [illegible].

SILVANUS PHILLIPS THOMPSON was born at York in [illegible]. He was brought up under the [illegible] of [illegible] and from his [illegible] days was surrounded by [illegible] Quaker influences. His father who was a [illegible] in York for 44 years was a great [illegible] and [illegible] [illegible] his [illegible] for [illegible]. He attended his father's classes at Bootham School and seems to have done uniformly well all round. He next went to the Flounders Institute—a training school for teachers—at Ackworth, where he worked hard and took the London B.A. degree in 1869. In 1870 he was appointed junior science master at Bootham, a post which he held until 1875. It is recorded that his school lessons were admirable and were generally illustrated by artistic diagrams drawn by himself. Gaining a scholarship at the Royal School of Mines he came to London and studied under Guthrie, Huxley, and Sir Edmund Frankland. In 1875 he took the London B.Sc. degree, being bracketed first in honours. The same year also he joined the Physical Society of London, with which he was ever after closely associated. In 1876 he went to Heidelberg, attending lectures by Bunsen and Quincke and at the same time perfecting his conversational knowledge of German.

In 1876 he was appointed to the Chair of Physics at the University College, Bristol, a post which he held for nine years and where he did most valuable work. In 1881 he married Miss Jane S. Henderson of Pollockshields, Glasgow, an event which contributed in no small degree to his subsequent success and happiness.

The work of Thompson's which had the greatest success was his "Elementary Lessons in Electricity and Magnetism" published in 1881. The writer remembers using it as a textbook for first-year medical students in 1887, and how admirably it answered its purpose. This book ran through some 40 editions and reprints. In revising the last edition he received able help from his daughter Helen G. Thompson, B.Sc. In 1882 he was elected a Member of the Society of Telegraph Engineers and Electricians. During this period he studied electrical problems assiduously and in 1884 published his epoch-making work "Dynamo-electric Machinery: a Manual for Students of Electrotechnics." Practically every designer of electrical machines has gleaned his first information on the subject from this work. In the numerous editions and expansions of the work which subsequently appeared he has amplified and improved much of the original edition. Still the first edition contains nearly all that matters, and the theorems and ideas incorporated in it are still to be found in all the recently published books on design. The success of the book was instantaneous. It was much appreciated in the universities, and many young men were first attracted to engineering studies by reading it. In the preface the author carefully points out that the mathematical theory of the dynamo can only be written when the true basis on which it should be founded is discovered. This basis is the exact law of the induction of magnetism in the core of an electromagnet. To many writers this had proved an insuperable obstacle. But Thompson proved that although the exact law had not yet been given by a mathematical formula, yet an approximate method could be given which was of the greatest value in practical design.

In 1885 Thompson was elected Principal and Professor of Physics and Electrical Engineering in the City and Guilds of London Technical College, a post which he held till his death on the 13th June, 1916. As a professor, whether as a teacher or as an original investigator, he was equally admirable. His pupils, many of whom are scattered all over the world, remember him with the greatest affection and pride. His powers of exposition were almost unrivalled and his kindly and sympathetic help and advice made his students love as well as admire him.

In 1886 he was elected a Member of the Royal Institution in Albemarle-street, where he spent many of the happiest hours of his life with his friends or in hearing or giving scientific lectures. In 1887 he communicated to the Institution of Electrical Engineers a paper on Telephonic Investigations, and in the following year another on Influence Machines.

In 1890 Thompson delivered the Cantor Lectures to the Society of Arts, the subject being the electromagnet and electromagnetic mechanisms. He subsequently expanded the lectures into a book to which his brother, Dr. J. Tatham Thompson of Cardiff, contributed a chapter on the use of the electromagnet in surgery. The book is admirably lucid, and many difficult problems are successfully attacked. In several cases also his conclusions have formed the starting-point for other investigators, and the good seed he sowed has borne abundant fruit.

In 1891 he was one of the honorary Vice-Presidents of the Electrical Exhibition at Frankfort, and in the same year he was elected a Fellow of the Royal Society. He was one of the British Delegates to the Electrical Congress at Chicago in 1893. At this Congress he read a paper on a method for diminishing the distortion of the electromagnetic waves in submarine cables used for telephony. The method was to insert inductive shunt circuits or leaks across the two lines of the cable or between the line and the earth. It undoubtedly equalizes the "attenuation" at different frequencies, and so improves the clearness of the articulation. Unfortunately, however, it greatly diminishes the loudness of the sound. The method is a perfectly valid one and useful in certain cases, but the method perfected by Pupin some years later is the one now adopted in practice. In this method inductive or "loading coils" are inserted in series in the line. Thompson, however, was the earliest pioneer of ocean telephony and his paper attracted world-wide attention.

In 1894 the University of Königsberg conferred on him the honorary degree of Doctor of Medicine and Surgery. In 1895 he gave the Cantor Lectures, choosing the Arc Light as his subject. His "Polyphase Electric Currents and Motors" was published in 1896 and in the same year he gave Royal Institution lectures on "Light, visible and invisible." These were published in book form and have given pleasure and instruction to a very wide circle of readers. In 1898 he read a valuable paper to the Institution on "Rotatory Converters." No small part of our present knowledge of the subject was first given in this paper.

In this year also was published in the Century Science Series his biography of Faraday. Thompson's sympathetic insight into the motives governing Faraday's life and his appreciation of the immense debt which the world owes to his memory made him the ideal biographer. In his preface he says, "In the recollection of such as have survived him, his image lives and moves, surrounded with gracious memories, a vivid personality instinct with rare and unselfish kindness." Surely these words apply also to Silvanus Thompson.

In 1899 he was elected President of the Institution, a post which he most worthily filled. Much of the advice which he gave in his Presidential Address we have adopted. He advocated both the mutual co-operation of scientific workers and the combination of electrical engineers in active union. "When we speak," he said, "in the name of the united profession, with the weight of the whole industry to emphasize our views" we can accomplish much for the good of the profession and also for the country.

In the battle of continuous-current versus alternating-current systems Thompson took a leading part. He felt most strongly on the way the managers of the Metropolitan Railway decided to use continuous current. He was most scornful about the so-called experiments on electric traction on this railway. In his opinion it was simply a throwing away of £30,000. When we can predict with absolute certainty what will happen it is surely pure waste to go to the cost of making the experiment. Thompson's ingenious system of electric traction by surface contact studs was described by Miles Walker in a paper to the Institution in 1899. If the local authorities in this country had made a firmer stand against overhead wires this system would probably have become popular. The danger of the studs being left alive after the car had passed over them was entirely obviated.

In 1900 Thompson was elected a member of the Senate of London University, and he was also elected the first President of the Röntgen Society. This Society has done invaluable work in perfecting apparatus and methods for X-ray photography, and consequently its work has indirectly been of almost priceless value in saving lives and obviating human suffering.

In January 1901 Thompson gave a lecture on Faraday (in German) to the Urania Society in Berlin, and in June of the same year gave a very interesting Boyle lecture at Oxford on "Magnetism in Growth." A few years afterwards he was commissioned to write the official biography of Kelvin, whom he regarded as the greatest scientist of the nineteenth century, just as he claimed Faraday as "beyond all question the greatest scientific expositor of his time." Kelvin helped Thompson in the first stages of the work, but he died before it was finished. In 1908 Thompson gave the first Kelvin lecture, and in 1910 was published the "Life of William Thomson, Baron Kelvin of Largs."

In 1910–11 he delivered the Christmas lectures on Sound at the Royal Institution. In 1911 he was an honorary Vice-President of the Electrotechnical Congress at Turin. In 1912 he was given the honorary degree of LL.D. by Birmingham University and was elected President of the Optical Conference. In 1913 Bristol University made him an honorary D.Sc.

In 1914 the tragedy of War broke out. To a man of his temperament imbued with such an enthusiasm for humanity and actuated only by the highest ideals the horror of it all impressed him in a transcendent degree. Yet he never lost faith although he gazed wistfully on the past as the shadows lengthened. When the final call came on the 13th June, 1916, he was thoroughly prepared, his house in order and his life's work done.

It is too early yet to appraise Thompson's work, but that part of it which was of most immediate value in his [illegible] He worked whole-heartedly for the advancement of our industry and profession, and as a direct means to [illegible] our Institution was better known and certainly none was [illegible]

[illegible] that of a book collector. No one had a greater love for [illegible] [illegible]ing interest. His wonderful collection of books on [illegible]y and magnetism is perhaps the most valuable in the kingdom. It consists of about 13 000 items, includ[illegible] books were published prior to 1825. Many of them are of interest, not only as showing the ideas about electricity and magnetism current in past centuries, but also because of special interest attaching to special copies. For instance, the memoirs of A. M. Ampere, "the Newton of electrodynamics" on the mutual action between two electric currents, contains Ampère's autographic inscription. [illegible] "Dialogus de Systemate Mundi" is the copy [illegible] and marginal notes. One of the books has the Aldine Anchor Mark in one of its rarest forms. Some belonged to Faraday, Gilbert, S. T. Coleridge, Delaunay, Volta, Archdeacon Barlow, Ridley, and others. Many are quaint and rare, and some are unique. To Thompson they were all well-known friends. In addition the library contains some 200 autograph papers of eminent scientific men and [illegible]

Lady Wilson, wife of Sir Roland K. Wilson, of Richmond, and daughter of Richard Phillips, F.R.S., who was Thompson's great-uncle, presented him with the letters Faraday wrote to her father.

Thompson's old friends thought that the best memorial of him would be to purchase his library from his executors and house it at our Institution, where it would be available for all desirous of study. It is most gratifying to know that arrangements have now been made for this to be done.

Thompson was always a warm advocate of technical education. In 1878 he read a paper on the subject at Cheltenham, and in the following year he proposed a scheme for a central institution for technical education in London, and explained the French system of apprenticeship schools. In his later years he was insistent on the urgent necessity of the closest co-operation between science [illegible]

"Belittle the teachings of science; ignore the expert [illegible]; carry on your works without him; if [illegible]n, pay him less wages than you pay a [illegible] who know no science. Then, when after years of this [illegible]kens come home to roost, and you find [illegible] It was so before the War; it will be so after it."

Thompson wanted every kind of improved condition for the worker, but most of all he wanted him to know science, for, in his opinion, upon this everything else depended. A few weeks before his death he said: "We are twenty years behind the States in our appreciation of the importance of science to industry. . . . Until we have made good for backwardness and blindness it will be mostly idle to talk of Great Britain capturing the industries which have been destroyed on the Continent of Europe by the great war. . . . In persistent collaboration and co-operation of industry with science lies the road to progress."

As a popular lecturer Thompson was unrivalled. Some 20 years ago he gave a lecture in the Carpenters' Hall on the future of Electricity, in which he described in a most entrancing way the industrial revolution that would ensue when electricity was used universally. The hygienic factories, the workpeople conveyed rapidly to their suburban homes, the small manufacturer with the aid of cheap power and assisted by his family well able to compete successfully with the factory, the absence of smoke, the roof gardens, etc., were all described in the most realistic and convincing way. One felt that electricity was on the point of revolutionizing the world.

In optics, more particularly in photometry, Thompson took the greatest delight. Some years ago he had to give expert evidence at the Law Courts as to the relative merits of various types of reflectors. The writer remembers him coming to the Faraday House laboratories to check the numbers obtained by the various experts. It was an education in itself to see how he verified their figures and tested them in every possible way.

He loved music and had an accurate musical ear. The valuable paper which he read to the Physical Society in 1910 on "Hysteresis Loops and Lissajous' Figures" was a happy mixture of magnetism, sound, and mathematical theorems. In solving mathematical problems and inventing new mathematical theorems he took the keenest delight. He did most excellent work, for instance, in simplifying Runge's method of practical harmonic analysis. He was dissatisfied, however, with the accuracy obtainable by this method. He then invented the series method of harmonic analysis. The writer remembers how pleased he was when he first discovered it and with what mutual pleasure we discussed it. He greatly appreciated the lectures which Dr. Kennelly of Harvard gave at the Institution some years ago. In proposing a vote of thanks to him he expressed himself, as usual, most happily. He said that he felt constrained to exclaim "Great is the Hyperbolic Angle and Kennelly is its Prophet." He took a keen interest in hyperbolic trigonometry, and the writer thinks that he contemplated at one time writing a little treatise on the subject.

As a Past President of the club which has the quaint title of "The Sette of Odd Volumes," Thompson took a great interest in general antiquarian literature. In 1914 he contributed to the *Proceedings* of the British Academy a most interesting paper on "The Rose and the Winds: the Origin and Development of the Compass Card." As a poet he attained some distinction. His monodies on Matthew Arnold and Tennyson were excellent. The following lines from the former may be appropriately quoted :—

"The eager spirit pent within thy breast
Hath passed from doubt to sight ;
Hath found the awaited spark from heaven descend ;
The light thou soughtest shining clear in view
When strange and vain the earthly turmoil grew,
And night has fallen as welcome as a friend."

As an artist Silvanus Thompson attained distinction, several of his works being exhibited in the Royal Academy. He began sketching in water colours when 18 years old. He was particularly successful in painting glaciers, but he has left pictures of landscapes in Scotland, Suffolk, Whitby, the Black Forest, the Rocky Mountains, Arolla, Saas Fée, and the Austrian Tyrol. On these painting excursions he was absolutely happy. The last of these golden holidays was spent in the Dolomites in 1914 just before the War broke out, and alas he then laid down his brush for ever.

To the Institution of Electrical Engineers the loss of Professor Silvanus Phillips Thompson in the plenitude of his powers is most grievous. He has left us heavily in his debt. His work lives and will continue to live. As the years roll on we shall ever gratefully remember his enthusiasm and kindly sympathy. His memory is a precious possession.

He is survived by his widow and four daughters. His youngest daughter, Irene, is the wife of T. E. Harvey, M.P., late Warden of Toynbee Hall.

The writer has to thank Mrs. Thompson, Lady Wilson, and Mr. W. M. Mordey for kindly giving him information. He has also to acknowledge his indebtedness to a deeply interesting article by G. N. on "Professor Silvanus Thompson and his Message" which appeared in the *Friends' Quarterly Examiner.*

A. R.

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(P) indicates a reference to the general title or subject of a paper or address.

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